The risk-return trade-off to diversified agriculture in Malawi: A quadratic programming approach

by

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Declaration

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Summary

The rapid growth in the human population has sparked shifts in the way agricultural sectors have evolved in different countries. Most developed countries and those with a commercially driven agricultural sector have placed emphasis on increasing productivity in a bid to 'produce more for less'.

Developing countries, by contrast, are often dominated by subsistence agriculture where the focus lies on ensuring household food security rather than profit maximisation. Malawi falls into this category with a vast majority of the working population involved in agriculture – more specifically, in the smallholder sub-sector. The risk of crop losses in these countries has dire consequences for people reliant on these crops for their everyday meal. Minimizing such risk in countries like Malawi is therefore of paramount importance.

Many studies, such as the one conducted by Ibrahim (2015), place diversification at the heart of risk management within the agricultural context. Consequently, this study investigated the use of diversification as a tool to minimise the levels of risk faced by smallholder farmers in Malawi.

Studies by Mango, Makate, Mapemba and Sopo (2018) and Kankwamba, Mapila and Pauw (2013) analysed the determinants of diversification in Malawian agriculture and the current levels of diversification within the country's agricultural sector. Their results provided insight into the factors influencing diversification and indicated a bimodal distribution for the number of crops grown – peaking at three as well as one. Evidently, the importance of diversification has already reached Malawian smallholder farmers.

However, minimal research has been done into the optimum diversification strategies for these farmers to implement on the smallholder level. Some success optimising cropping portfolios for smallholder farmers in Malawi was found using Quadratic Risk Programming. However, that particular research called for an updated and more data accurate investigation. Accordingly, this study implemented the Quadratic Risk Programming model on a large sample of smallholder farmers in the southern region of Malawi. Six models were created, varying the size of the smallholder field and the capacity of the farmer to apply inorganic fertiliser. Five primary crops, namely maize, soybeans, groundnuts, common beans and sweet potatoes, were identified and their performance was analysed over three consecutive years. Each model included a variance-covariance matrix, incorporating the relationships between crops to derive optimized cropping portfolios according to the desired level of risk exposure.

For small farms, the results showed that, of the available 2 acres, 1,3 acres should be allocated to maize and the balance shared between groundnuts and beans. A ratio favouring beans gave lower risk than when groundnuts were favoured. However, models for medium and large farms recommended an

average allocation of 50 percent of their arable land to groundnut production. In consideration of food security, all models contained a minimum threshold for maize growth. The results for all fertilised farm models indicated sweet potato growth at the maximum constraint, prompting the recommendation for improved storage and marketing facilities for this crop in Malawi.

Finally, recommendations were made regarding the use of the state-owned marketing platform, ADMARC, to protect farmgate prices and stimulate an agricultural environment conducive to the findings of this thesis.

Opsomming

Die vinnige groei van die menslike bevolking het na verskuiwings gelei in die manier waarop landbousektore in verskillende lande ontwikkel het. Die meerderheid ontwikkelde lande en dié lande met ’n kommersieel gedrewe landbousektor benadruk verhoogde produktiwiteit in ’n poging om ‘meer vir minder te produseer’.

Ontwikkelende lande, in kontras, word in baie gevalle gedomineer deur bestaanslandbou, waarin die fokus val op die versekering van die huishouding se voedselsekuriteit eerder as winsmaksimering. Malawi val binne hierdie kategorie, met 85% van die werkende bevolking wat in landbou betrokke is – meer spesifiek in die kleinboersektor (Drope, Makoka, Lencucha & Appau, 2016). Die risiko van gewasverliese in hierdie lande hou ernstige gevolge in vir mense wat op hierdie gewasse staat maak vir hulle daaglikse kos. Die minimalisering van sulke risiko’s in lande soos Malawi is dus baie belangrik.

Baie studies, soos die een van Ibrahim (2015), plaas diversifikasie sentraal tot risikobestuur in die landboukonteks. Gevolglik het hierdie studie ondersoek ingestel na die gebruik van diversifikasie as gereedskap om die vlakke van risiko wat deur kleinboere in Malawi ervaar word, te minimaliseer.

Studies deur Mango, Makate, Mapemba and Sopo (2018) and Kankwamba, Mapila and Pauw (2013) het die determinante van diversifikasie in die Malawiese landbou en die huidige vlakke van diversifikasie in die land se landbousektor geanaliseer. Hulle resultate verskaf insig in die faktore wat diversifikasie beïnvloed en het ’n bimodale verspreiding vir die aantal gewasse wat gekweek is, getoon – wat op drie sowel as een ’n hoogtepunt bereik het. Klaarblyklik is Malawiese kleinboere reeds bewus van die belangrikheid van diversifikasie.

Daar is egter minimale navorsing oor die optimum diversifikasiestrategieë vir hierdie boere om op die kleinboervlak te implementeer. Msusa (2007) het ’n mate van sukses behaal met die optimalisering van oesportefeuljes vir kleinboere in Malawi deur gebruik te maak van Kwadratiese Risikoprogrammering (Quadratic Risk Programming). Sy navorsing het egter die behoefte aan ’n opgedateerde en akkurater data-ondersoek uitgewys. Gevolglik het die huidige studie die Kwadratiese Risikoprogrammeringsmodel op ’n groot monster kleinboere in die suidelike streek van Malawi geïmplementeer. Ses modelle is geskep, met verskille in die grootte van die kleinboere se grond en die vermoë van die boer om anorganiese bemesting toe te dien. Vyf primêre gewasse, naamlik mielies, sojabone, grondbone, gewone bone en

patats, is geïdentifiseer en hulle prestasie is oor drie opeenvolgende jare geanaliseer. Elke model het ’n variansie-kovariansie matriks ingesluit wat die verhoudings tussen gewasse geïnkorporeer het om geoptimaliseerde oesportefeuljes volgens die gewenste vlak van risikoblootstelling af te lei.

Vir klein plase het die resultate getoon dat 1,3 hektaar van die beskikbare 2 hektaar aan mielies toegeken moet word en dat die balans tussen grondbone en bone verdeel moet word. ’n Verhouding ten gunste van bone het gelei tot minder risiko in vergelyking met grondbone. Modelle vir medium-grootte en groot plase het egter ’n gemiddelde toekenning van 50 persent van hulle bewerkbare grond vir grondboonproduksie aanbeveel. Met betrekking tot voedselsekuriteit het al die modelle ’n minimum drempel vir mielies bevat. Die resultate vir al die bemesde plaasmodelle het patatgroei teen die maksimum beperking aangedui, wat gelei het tot die aanbeveling dat verbeterde stoor- en bemarkingsfasiliteite vir hierdie gewas in Malawi verskaf moet word.

Laastens is aanbevelings gemaak oor die gebruik van ADMARC, die bemarkingsplatform in staatsbesit, om plaashekpryse te beskerm en ’n landbou-omgewing te stimuleer wat bevorderlik is vir die bevindinge van hierdie tesis.

"Forget all the reasons why it
won't work and believe the
one reason why it will"

– Ziad K. Abdelnour

This thesis is dedicated to my sister

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Chapter 1: Introduction

The reliance on agriculture in the African continent is prominent. The sector serves as a backbone to many of the African countries' economies; providing jobs, foreign earnings and importantly, food for the local populations. With the African population doubling in the last 30 years, pressure for land is mounting and the importance for agricultural productivity to match the growth is paramount. However, agricultural production in Africa has not kept pace with the rapid population growth (Blein, Bwalya, Chimatiro, Leturque & Wambo-Yamdjeu, 2013).

The result is widespread hunger and growing poverty levels across the continent. Climate change and the increased frequency of abnormal weather events are also contributing to the challenges of agricultural productivity and the resultant consequences. Given the increasing demand for food and evolution of widespread hunger, Beddington (2009) proposed the perfect storm scenario, which predicts the by the year 2030, the world will need to produce 50 percent more food than it was at the time of his research in 2009. An integral part to fulfilling this requirement comes through improving the efficiencies and minimizing the potential losses faced by the agricultural sectors in the respective countries.

While ample research has been conducted in Africa on agricultural efficiencies and how one can 'produce more for less', its counterpart, which is focusing on the minimization of potential losses and risk exposure, has received less attention. The risk of agricultural losses can either be pinned to production risk or market risk. The increased frequency of abnormal weather events troubling the production side of agriculture combined with the lack of suitable infrastructure such as irrigation exposes such production risks.

Additionally, the overwhelming market power established by the mega producers such as China, has created an environment in which the control held by a single farmer is diminishing more and more. Besides the competitive urge of a country to compete on the international scale, the same risk elements are even more tangible on the farm level for a farmer trying to sustain him/herself and feed their family. In Africa, where hunger and poverty are bountiful, the risks of crop losses and failures are exemplified when their lives depend on it.

1.1 Background to the Study

The ability of a country and its people to absorb the effects of agricultural losses, be it through production or market failures, varies greatly. When agriculture forms the backbone of a country's economy, the effects of such losses are felt on a much greater scale than a country with a more diversified economy.

Within Africa, the reliance on agriculture is substantial. In countries where the agricultural sector comprises of a large commercial sector, such as South Africa, the effects of losses reflected on a macro-economic scale will be evident. In countries where small-scale subsistence agriculture dominates the sector, the people themselves bear the direct effects of crop losses and are often left in the face of poverty and hunger. Malawi is one such country where the latter holds.

1.1.1 Country profile: Malawi

Malawi is a country dubbed 'the warm heart of Africa,' which is testimony to its friendly, welcoming people. However, behind the smiles, the country is ranked amongst one of the poorest with the nation being the fifth most aid-dependent country in the world (Mwanamanga, 2015). Malawi may be small, but it contains nutrient rich soils ideal for agricultural production. Almost a third of the country's GDP can be accounted for by agriculture. In addition to this, almost 85% of the total labour force is involved in agriculture, with majority of these being in the smallholder sub-sector (Drope *et al.*, 2016).

The dependence of agriculture in the country is apparent; such reliance can almost be further devoted to the dominance of a single crop – tobacco. Following independence in Malawi and the liberalisation of the tobacco sector, smallholder farmers committed themselves fully to the crop. Many farmers abandoned their other crops and Malawi soon found itself as one of the largest producers of burley tobacco in the world.

1.1.2 Tobacco reliance in Malawi

Malawi has a fragile and struggling economy, kept alive almost solely by its agricultural sector. Tobacco in particular accounts for approximately 60% of the annual export earnings, making Malawi the most tobacco-reliant economy in the world (Prowse, 2009). Tobacco alone contributes roughly 13% to the country's GDP and indirectly provides employment for a significant proportion of the country's working population (Chirwa, 2011). Thus, tobacco has earned the 'green gold' label in Malawi. The Times Group confirmed that in 2020, the green gold crop still contributed two-thirds to the country's foreign earnings (Mzungu, 2020).

Historically, six varieties of *fodya* (tobacco) have been grown in Malawi. It is the flue-cured and burley tobacco varieties which are the most momentous, with the latter accounting for more than 90% of the country's total tobacco production (Chirwa, 2011). Following the liberalization of the tobacco market in 1992, the Malawian smallholder farmers grasped the opportunity to produce the cash crop and by the end of the 1990s accounted for 60% of the national production (Prowse, 2003).

The fully committed shift toward the tobacco crop by many smallholder farmers meant their livelihoods became solely reliant on the crop. Their risk of hunger and poverty correlates directly to the risk of a tobacco crop failure. While the smallholder farmers have some control over their agronomic practices and other production factors, they have virtually no control over the heavily regulated tobacco market. The tobacco sales take place through two parallel systems – auction market and contract market (or direct buying) by the registered buyers (Chirwa, 2011).

Both systems are heavily regulated and dominated by two primary buyers who together purchase between 60 to 70% of the tobacco produced annually in Malawi (Drope *et al.,* 2016). The large number of smallholder tobacco growers and the select buying companies automatically transfer a significant amount of bargaining power away from the smallholder farmers.

The volatility of the tobacco prices which are further plagued by future projections by industry role players who hint towards a diminishing price trend (AHL Group, 2019). Such predictions are based on a declining world demand for tobacco and rising health-related lobbies. This is putting Malawi and more importantly the smallholder farmers, in a perilous position. The effects of the price volatility in the tobacco industry and future projections mirror the livelihoods of the people who are dependent on the crop.

Considering the financially constraining environment within which a Malawian smallholder farmer exists, their tolerance to risk is low and any losses are greatly felt. The reliance on tobacco exemplifies such a risk, characterized by its volatility and potentially dire future trends. The combination of a dominant livelihood reliance on a risky crop and the already dire poverty level of those livelihoods, leaves little room for failure. Simply put: if the crop fails, poverty will tighten its grip on the population relying on tobacco.

The situation in which Malawi found and still finds itself, has drawn countless efforts from researchers and policy makers to create an environment which steers the population out of its ominous reliance on tobacco. Other cash crops such as tea are contributing to their share for foreign exchange earnings for the country. However, most tea production is limited to the larger estates.

On the smallholder level, many studies have identified the factors that determine and/or encourage farmers to diversify away from tobacco. Subsidy programmes, among other tools, have been implemented in the country to increase the ease and appeal of producing other crops such as groundnuts and beans. Other studies highlight the existent level of diversification already in Malawi and what influence it plays on the rural livelihoods. Inevitably, increasing the level of diversification reduces the potential risk of total crop failure, whether from turbulent markets or climate-related incidences.

The benefits of diversification are not limited only to smallholder tobacco farmers, its reach can extend to all the smallholder growers. The risk of crop failures does not exempt all other crops besides tobacco. The subsistent environment in which most smallholder farms operate in Malawi outside of the tobacco producers is widespread.

Maize forms the staple food crop and is grown across the country. Groundnuts, soybeans, sweet potatoes, common beans, and cassava are among the other crops popular to the smallholder farmers. Any surplus of a food crop not consumed in the household is sold in the local market; these local markets house the potential risk of market risk, such as inadequate prices due to an oversupply. In the presence of a diversified crop spread, a smallholder farmer reduces his/her risk of falling victim to the exploited local market prices of a single crop.

1.2 Problem Statement

Many smallholder farmers in Malawi, and their livelihoods, have become reliant almost purely on tobacco. With continuous fluctuations and downward trends in the tobacco prices, the increased occurrence of crop losses has made the risk exposure to tobacco farmers unsustainable. When the tobacco crop disappoints their livelihoods take a direct strain. Growing a combination of crops within a single household will reap benefits with reference to decreasing the potential of an overall crop failure.

The cries for diversification in Malawi have been heard and addressed to an extent by researchers and policy makers. As a result, smallholder farmers are being encouraged to diversify and the platform for such a transition exists. However, little research has been done to identify exactly how a farmer should diversify. There is a need to identify optimum crop portfolios, which are applicable at the smallholder farm level and ensure sufficient returns while matching varying farmers’ desired levels of risk exposure.

1.3 Objectives of the study

The inability of smallholder farmers in Malawi to bear the negative impacts of potential risks associated with crop failures is apparent. Considering this, and the country’s tobacco background, this study elaborates on earlier studies which promote the existence of diversification in Malawi. The objectives of this study are two-fold and reach beyond other studies, which simply provide a theoretical framework for diversification in Malawi.

The primary objective of this study is to identify crop portfolios which minimise the level of risk a farmer is exposed to whilst still achieving sufficient returns. The objective answers the question as to how a farmer should diversify on the smallholder farm level in Malawi. The second objective of this study is to incorporate the results derived from the primary objective into recommendations that may allow the optimized diversification strategies to be implemented efficiently. Overall, this study identifies how to use diversification as a tool to minimise risk in smallholder farming in Malawi.

1.4 Hypothesis of the study

The study proposes the following hypotheses:

- The larger the number of crops in a portfolio the less the overall portfolio variance.
- Two crops with a negative covariance will be favoured when grown together in a portfolio.
- Maize allocations will be limited to the amount necessary to ensure food security and not grown in surplus as a cash crop.

1.5 Approach and methodology of the study

To analyse the relationship between risk and return while aiming to provide optimized cropping portfolios for smallholder farmers in Malawi, the study makes use of quadratic risk programming (QRP). QRP is the more complex cousin to the commonly used linear programming approach when dealing with optimisations. The QRP method can incorporate a risk factor in the form of a variance-covariance matrix to include the interrelationships between crops in the optimisation mix.

To formulate the QRP model requires a data intensive spread providing comprehensive historical data across a minimum of a three-year period. Fortunately, smallholder agricultural corporations in Malawi were able to assist and provide inclusive data. Crop specific budgets are derived and compared amongst each other in the variance – covariance matrix, which are inputted into the model. The results generate an optimal crop portfolio, which corresponds to a prespecified expected return and a consequent level of variance (risk). With further parametric adaptions to the model, an efficient risk-return frontier is created.

To increase the accuracy of the results, the study narrows its focus to a more confined study area. The study bases its approach on the southern region of Malawi, which hosts the largest proportion of the country’s population. This studies’ spotlighted region in the south includes the major city of Blantyre and the country’s previous capital, Zomba.

1.6 Outline of study

This thesis proceeds as follows: chapter 2 presents a review of the literature on diversification and the trade-offs between risk and return. The chapter also analyses literature reviews of methodological uses of mathematical programming including QRP to derive such a risk-return trade-off. Chapter 3 provides a detailed description of the quadratic risk programming implemented in the study.

Chapter 4 then provides a discussion of the data and the methods used to fulfil the study and address the research objectives. Chapter 5 displays the results with a corresponding discussion. Finally, chapter 6 provides the conclusion. This chapter includes a summary of the thesis and the findings thereof. Chapter 6 concludes by providing recommendations for future research to be based off the findings and the methods of this study.

Chapter 2: Literature review

2.1 Introduction

This chapter provides an introduction and overview of the countless components which form a part of this study's journey. It also analyses the different mathematical programming models used in other studies to answer questions similar to that of this studies research objectives. Furthermore, other research within the diversification scope targeted specifically at Malawi's agriculture is also examined.

2.2 Trade-off

The balancing of factors which are not attainable at the same time, creates a scenario in which a decision-maker must choose which factors to surrender and which to make a reality, such a scenario is termed a 'trade-off' (Galafassi, Daw, Munyi, Brown, Barnaud & Fazey, 2017). In Economics, the term 'trade-off' is seen to reflect an opportunity cost i.e., the most preferred possible alternative. For example, when two factors are compared and only one can be chosen, the factor which is given up represents the opportunity cost; such is the case when comparing risk and return.

The age-old phrase 'high risk high reward' did not develop without factual backing. A trade-off between risk and reward/return is omnipresent amongst all decision-makers; from a driver having to choose to travel along a shortcut or a company considering a capital investment, to name a few. A driver may be at risk that he gets stuck on the shortcut, or the company is at risk that the capital investment does not earn the desired result.

To many people, their definition and interpretation of risk is different. Inevitably, risk is the exposure to unfavourable consequences or in the words of Lowrance (1976), 'risk is the measure of probability and the weight of undesired consequences. A quick differentiation between risk and uncertainty is necessary as the two are often assumed the same. Opposed to the predictable unfavourable consequences faced when at risk, uncertainty pertains to a lack of information about the objective probabilities in the future (Chirita, Sarpe & Toma, 2012).

On the other side of the coin, creating the environment for a trade-off, lies the return. The benefit and/or gain obtained because of a decision-maker's choice is called a 'return'. The term is best used in the economic world, where return is defined as the gain obtained as a result of holding a certain asset over a period of time (Ibrahim, 2015). The return on an investment is the interest paid to the investor or dividends received over the holding period.

However, looking back at the example of the driver considering taking a shortcut, the return if he is successful in his bid to take the shortcut would be that of fuel and time saving. Evidently, the notion of risk and its rewarding counterpart, return, create a trade off in most walks of life. It is the economic/financial activity surrounding the multidimensional attitude towards risk and return which is more complex and bears greater potential for losses or gains.

When a decision-maker is allocating their resources among investment opportunities, their investment decision is split into two parts as defined by Merton (1977). The initial part is 'consumption saving', whereby the individual decides how much to use for current consumption, and the second part is how much he is willing to put away for future consumption (Merton, 1977). Once an allocation of the investor's resources for investment into future consumption has been made, they select amongst the available investment opportunities to create an investment portfolio – a compilation of their savings amid the available investments. The image created here is where the source of the investor's return is founded in an idea known as investment theory. Of course, attached to the return is an element of risk and often a strong positive correlation exists between the rate of return and level of risk (Ibrahim, 2015).

2.3 Risk

There are two broad categories of risk that investors are exposed (Hotvedt & Tedder, 1978). The first is known as systematic risk, which is a result of economy-wide disruptions affecting all returns across the market. The second is unsystematic risk which occurs on a more micro level, caused by factors specific to the company or industry itself. A key element to be introduced is that of diversification, a process whereby spreading one's investments among different options i.e., not placing all the eggs in one basket. Although diversification cannot tackle systematic risk, it serves as a tool to reduce unsystematic risk (Ibrahim, 2015). Diversification therefore becomes an integral part of risk management, particularly in agriculture.

Since the development of agriculture from the early days of hunting and fishing to modern day agriculture, risk remains an inevitable feature of agriculture (Anderson, Hardaker, Lien & Huirne, 2015). Further to the broad categories of risk already identified, Barry, Elinger, Hopkin and Baker (2000) dissect the different types of risk into those pervasive in agriculture. The business risks faced by farmers include (1) production and yield risk (2) market and price risk (3) losses from disasters (4) social and legal risks (5) human risk and (6) risks of technological change.

In addition to these business risks, there are also financial risks which farmers are exposed to such as loans and other financial obligations (Barry *et al*., 2000). A combination of business and financial risks amplifies the potential losses faced by farmers. The development of risk management – of which diversification forms a crucial part, is important to minimise these risks. Having said this, risk is a part of everyday life and not something to run away from. Thus, the task rather is to manage it effectively. At the end of the day, it is often said that profit is the reward for bearing risk - no risk no reward (Anderson *et al.*, 2015).

Academic and policy research for agriculture in Africa sees diversification as a focus for risk management (Ibrahim, 2015). Ellis (2000) concluded that diversification bears positive attributes and as such, policies should be implemented to promote diversification in developing African countries. Within these countries, subsistence agriculture forms a crucial part of the livelihoods of a vast majority of the populations. Furthermore, the poor nature of the people means their inability to bear the costs of taking a risk is amplified. Therefore, it is important to consider the risk-return trade-off when designing risk management strategies among the smallholder farmers.

The nature of agricultural risks in Africa comes through mostly through variability and volatility. In fact, Africa is one of the continents in the world most affected by food price volatility and production variability (Demeke, Kiermeier, Sow *& Antonaci*, 2016). Among these African countries, Malawi stands out as one of a few with above-average levels of volatility (Demeke *et al.,* 2016). Almost 85% of the total labour force in Malawi is involved in agriculture, with the majority of these in the smallholder sub-sector (Drope*, Makoka, Lencucha & Appau,* 2016). Thus, it can be said that the risk of agricultural volatility is borne on the shoulders of almost the whole country.

The poverty-stricken nation has for decades relied almost solely on tobacco production. The crop, often dubbed ' the green gold', accounts for almost 60% of the country's foreign earnings, making it the most tobacco-dependent economy in the world (Prowse, 2009). Such dependence carries a burden of risk, particularly to the smallholder tobacco growers who after liberalization of the industry were responsible for almost two thirds of the nation's dominant tobacco variety – burley (Prowse, 2003). Recent health developments in the industry have seen the demand for tobacco slide and with this, the prices received by the tobacco farmers decrease year after year.

Consequently, the pressure of food insecurity is amplified among the farmers. In addition to this, agriculture in Malawi is predominantly rain-fed production, adding the risk and uncertainty of climatic conditions to the scenario (Mango *et al.,* 2018). To ensure sufficient returns and minimise food insecurity in Malawi, farmers will need to find ways to combat the risks they are faced with and broaden their reliance away from a single crop.

2.4 Diversification in Malawi

Research by Mango *et al.* (2018) in Sub-Saharan Africa, has shown that crop diversification is a tool to not only provide smallholder farmers with a diversified diet, but more importantly improves their income and food security. They studied 271 randomly selected smallholder farming households in central Malawi to evaluate the influence of crop diversification on household food security. Through interviews and structured questionnaires, they were able to collect the relevant data and analyse it using ordinary least square techniques and descriptive statistics. Their results showed that crop diversification (significant at a 1% level) has a substantial influence on food security (Mango *et al.,* 2018).

The findings support the recommendations of Ellis (2000), to promote crop diversification in African farming and more precisely Malawi. Mango *et al.* (2018) concluded that crop diversification is a viable option to ensure the establishment of a more resilient agricultural system for smallholder farming in Malawi. In an era where climate variability and volatile tobacco prices (shown in Figure 2.1) burden the smallholder farmers in Malawi, it is crucial for policy makers to provide farmers with the foundation on which to encourage diversification.

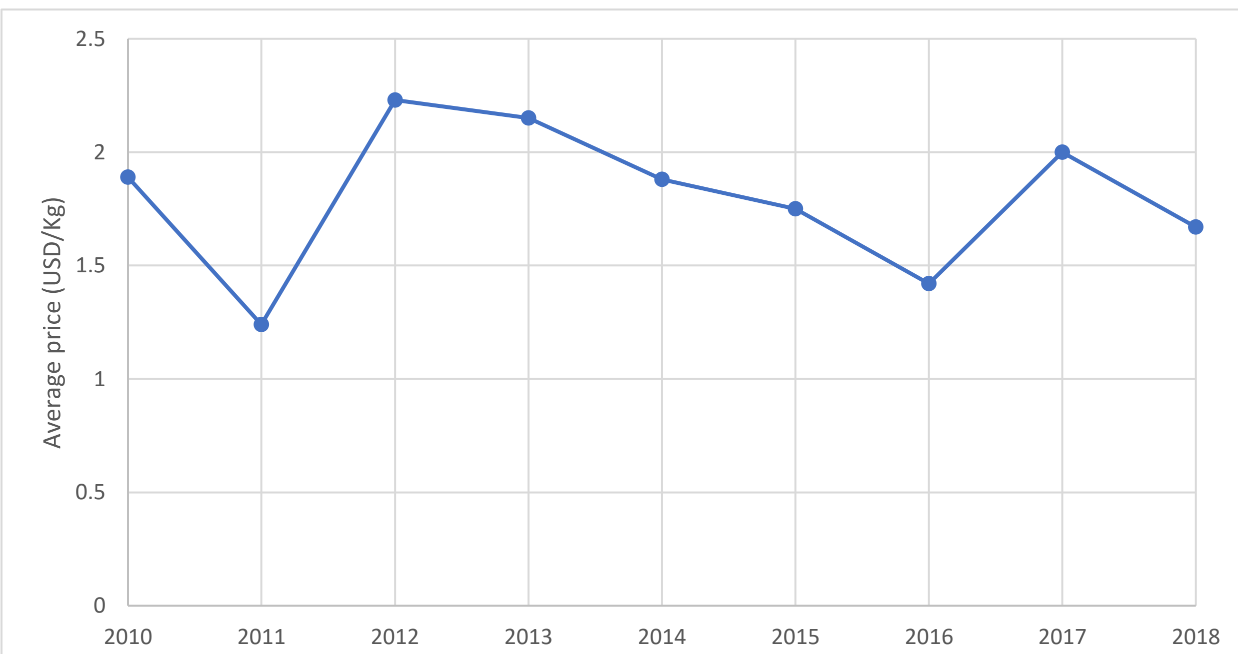

Figure 2.1 Average tobacco price in Malawi
Source: AHL Group (2019).

The benefits of crop diversification can be felt at both the micro and macro-economic levels. The macroeconomic level sees the benefits to the whole economy through increased resilience to economic shocks and overall growth and industrialization (Kankwamba, *et al.*, 2013). At the microeconomic level, increased crop diversification enhances food nutrition and raises household income levels, while permitting farmers with techniques to better adapt to the challenges and risks of climate change and price volatility (Kankwamba, *et al*. 2013). Of the two levels, it is the latter which is exposed to the amplified effects of the risk-return trade-off, whose outcome is crucial amongst the poor nature of the smallholder farmers in Malawi. Following this, Kankwamba *et al*. (2013) performed a study which identified the role of agricultural diversification in economic growth, food security and importantly – risk reduction.

At its simplest, horizontal diversification with respect to agriculture implies the addition of new farming activities to an existing agricultural enterprise (Kankwamba,*et al.*, 2013). Such diversification is only meaningful if sufficient resources are allocated to the new activity. Hence the study conducted by Kankwamba *et al*. (2013) analysed both the number of farming activities in the enterprise as well as the share of resources allocated to each. The study uses secondary data obtained from two Integrated Household Surveys conducted in 2004/05 and 2010/11, which consist of questionnaires aimed to provide poverty benchmarks but also include detailed agricultural statistics.

The agricultural statistics include figures regarding crop land allocation, crop production, and crop sales (Kankwamba, *et al*. 2013). A sample of roughly 20 000 households who reportedly allocated land to at least one or more crops, was analysed. The key variables included in the regression analyses were subjected to exploratory data analysis techniques to recognise distributions and identify outliers in the data. Once the data had been cleaned, it was run through the regression analysis (Kankwamba, *et al*. 2013). The study also identified and described some of the crop diversification indexes and indicators on which to base their economic analysis. Perhaps the most used measure of diversification among researchers is the Herfindahl-Hirschman index (HHI).

$$\mathbf{HHI} = \sum_{i=1}^{n} p_i^2 \; where \; p_i = \frac{A_i}{\sum_{i=1}^{n} A_i}$$

Let *A* represent land allocation (in hectares) to the i^{th} crop and p_i the proportion of land allocated to the i^{th} crop. Then HHI is the sum of the p_i's squared. The index considers both the number of activities (crops cultivated) and the ways in which the resources (or crop land) are allocated among them (Kankwamba, *et al.* 2013). The HHI takes a value varying between zero and one.

A score of one means the farmer inherits complete specialisation i.e. focuses on a single crop (Malik & Singh, 2002). As the score approaches zero, it indicates perfect diversification. The Simpson Index of Diversification (SID) and/or the Crop Diversification Index (CDI) is derived directly from the HHI and allows for direct interpretation of the results (Malik & Singh·, 2002).

$$\mathbf{SID} = 1 - \sum_{i=1}^{n} p_i^2 = 1 - HHI$$

As seen from the equation of HHI, the value of SID is not only influenced by the number of crops grown, but also by the proportion of land allocated to each respective crop. The SID is limited to a maximum value of 1 - 1/n for a finite number of crops *n*, when land is allocated equally among the crops. The SID is a more practical measure of diversification, as a higher index value implies a higher level of diversification (Kankwamba, *et al*. 2013).

The study done by Kankwamba *et al*. (2013) used a series of regression equations to assess elements of crop diversification in Malawi, using the SID as a dependent variable in each of the equations. The Tobit model – a regression model in which the dependent variable is censored in some way, was identified as the most appropriate of the estimates. It is especially suited to the regression analysis of crop diversification indexes like SID (Kankwamba, *et al*. 2013). The results of the SID estimates for Malawi in 2004/05 and 2010/11 are shown on Kernel density plot which is a non-parametric estimation of the probability density function.

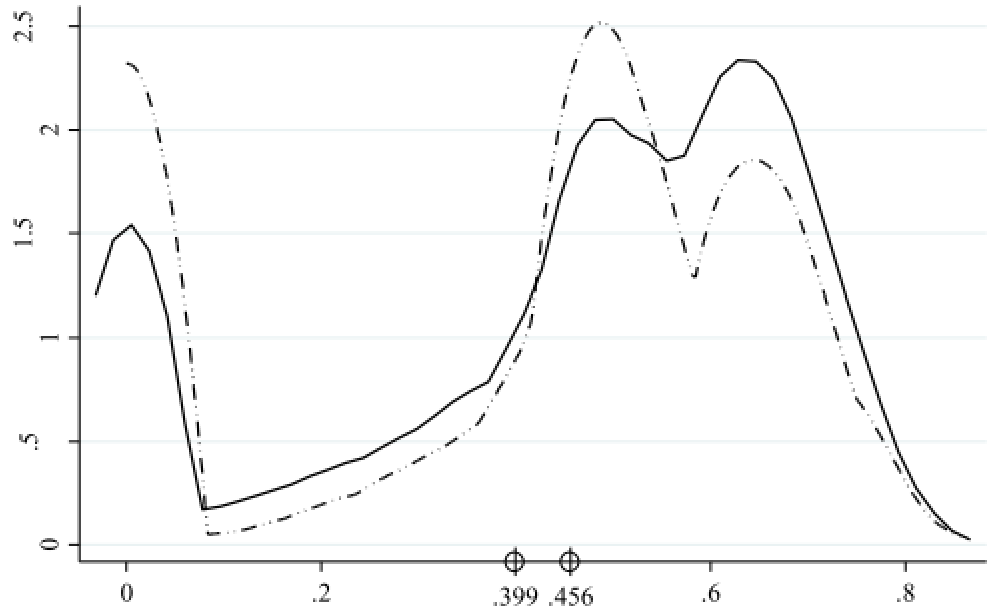

Figure 2.2 Simpsons index of diversification (SID)

——— 2004/05 - - - - - - 2010/11

Source: Kankwamba *et al.* (2013)

As seen in Figure 2.2, the y axis represents the frequency with which a certain SID value (x axis) is likely to appear in a distribution (Kankwamba, *et al.* 2013). The markers on the x axis mark the mean SID values in 2004/05 (0.456) and 2010/11 (0.399). Both surveys from the respective years reveal a similar shape in the distribution of SID values; the higher the SID value, the higher the level of diversification possessed by the farmer.

The peaks observed around the SID score of zero indicate a high density of farmers specializing in the production of only a single crop (n=1). Another peak is visible around the 0.66 SID score, which indicates three crops are grown (n=3), bearing in mind that under equal land allocation the SID is given by 1 – 1/n (Kankwamba, *et al.* 2013).

The mode (most common value) derived from both years analysed, is a SID value of around 0.5. This occurs when farmers split their land equally among two crops. Therefore, evident from the results, farmers in Malawi tend to prefer mono-culture farming or else if they diversify it will likely be with the addition of one or two more crops at most (Kankwamba, *et al.* 2013). A comparison between the two surveys reveals an increase in monoculture farming from 2004/05 to 2010/11, together with a decline in the number of farmers cultivating three types of crop. This suggests a decline in the farm level of diversification in Malawi between the two respective surveys. This is supported by comparing the lower mean SID value in 2010/11 to the higher SID mean in 2004/05.

The results of the Tobit model were used to highlight the determinants of crop diversification during the period of the two respective surveys in Malawi. Kankwamba *et al*. (2013) found household size, access to agricultural extensions, and distance to market and infrastructure to be the significant factors which positively contributed to crop diversification. The education level of the household head was found to have a negative relationship with crop diversification, which proved to contradict the findings of Mango *et al*.'s (2018) study and other similar studies in other countries.

It was concluded by Kankwamba *et al.* (2013) that following Malawi's low education standards, as farmers move from lower to higher levels of education, they significantly specialize. The results also suggest the overall effect of female farmers to negatively impact crop diversification compared to male-headed farming households. Access to credit was found to be statistically significant with a negative relationship to diversification. This suggests that farmers with a higher access to credit are less likely to diversify. Geographic location was also found to play a significant role in the level of crop diversification, varying according to the annual rainfall amounts (Kankwamba *et al.* 2013).

The study by Kankwamba *et al.* (2013) identified the levels of diversification found in Malawi and the determinants of such diversification. The levels were found to be rather low and showed signs of decreases between the two survey periods. The study makes policy recommendations to try and promote crop diversification, such as input subsidy programmes aimed at smallholder farmers specifically.

It is important to recognize the influence of agricultural extension services such as the Agriculture Sector Wide Approach (ASWAp), which emphasizes the elevation of crop diversification. ASWAp is an extension service aimed at increasing agricultural productivity with the ultimate goal of reducing nationwide poverty in Malawi (Mwanza, 2011). Kankwamba et al.'s (2013) study found access to agricultural extension services (ASWAp being among them), to have a positive influence on crop diversification in all models tested in the analysis.

Despite this, the study already indicated a decrease in the levels of diversification. Such extension services should be manipulated in such a way to create a platform which encourages decision makers to realize the maximum potential at the risk-return trade off when considering different diversification options. Increased diversification will ultimately contribute to a less erratic economic growth - due to the increased resilience to weather and/or price shocks, and long-term adaption strategies (Kankwamba, *et al*. 2013).

Whilst the study by Kankwamba *et al.* (2013) identified the level of diversification in Malawi and its determinants, the specific compilation of what successful diversification entails is blurry. A farmer diversifying between two or three crops which each continually fail to deliver results, is exposed to no less risk than an undiversified farmer whose thrown all their eggs into a single basket. The study by Mango *et al.* (2018) suggests that crop diversification, cattle ownership, access to credit and attaining of education lead to higher sources of income and reduced food insecurity, which provides a better clue towards diversification options. Although, the study is unable to give a detailed analysis of the particular diversification strategies mentioned.

As already mentioned, the aim of diversification in Malawi is to reduce the reliance on tobacco and additionally maize, and in doing so reduce the risk associated with specialization. Having said this, how does a smallholder farmer create a portfolio from a vast range of crops to not only reduce risk but still ensure sufficient returns? As touched on earlier, a portfolio consists of a make-up of all the chosen financial instruments from which an investor/decision maker expects to earn a return.

Markowitz (1952) introduced a revolutionary 'portfolio selection theory' which provides insight into the rules of the diversification of risky assets and recognizes the relationship between risk, return and portfolio diversification. The effectiveness of diversification to reduce risk is associated to the correlation between the returns of the agricultural activities. Given that the returns among activities in a portfolio are perfectly correlated, diversification will not have an effect on the amount of risk faced by the farmer (Markowitz, 1952). Markovitz based his theory on a few assumptions: 1) decision-makers (farmers) are rational and risk-averse with the goal of maximising their utility and minimizing their exposure to risk for any level of expected return; 2) markets are efficient and decision makers have access to perfect information on which to base their investment decisions (Ibrahim, 2015).

2.5 Mean-Variance efficiency criteria

Markowitz's (1952) portfolio selection theory provides a basis on which to analyse the trade-off between activities, with the notion of maximising revenue whilst minimizing risk in mind. How one measures risk and return becomes an important consideration. The evolution of an expected income-variance (E,V) frontier compared the expected returns associated with a portfolio and its corresponding level of risk. Expected income (E) is the standard measure of the return from a portfolio, whereas variance developed into an accurate measure of the level of risk.

Markowitz (1952) furthered his involvement in the subject when he proposed a way to use quadratic programming to derive a set of efficient E,V farm plans from which a farmer can choose (Thomson & Hazell, 1972). Quadratic risk programming became the first attempt to take explicit accounts of risk in mathematical programming formulations of a farming activity planning problem (Visagie, De Kock & Ghebretsadik, 2004). Thus, the quadratic risk programming established into an efficient tool used in portfolio analysis.

Kobzar (2006) performed a diversification strategy analysis on arable farms in the Netherlands. The objectives of this research were to analyse the farm-specific trade-off between expected income (return) and variance of income (risk). Moreover, the strategy analysis included risk as a variable in portfolio optimization using different risk programming models. Input data referring to yield, and costs was available on the Farm Accounting Data Network – a unique panel data set of information to per farm per crop in the Netherlands, for 718 available arable farms.

The sample size was further refined to fit the study's specific criteria which included: 1) The farms are 100% arable. 2) The land area cultivated remained constant over the observed period. 3) The land is 100% owned property. 4) The farms grew a particular stable crop set every year during the study period.

Once these criteria were applied, 218 farms were left for the analysis, from which ten farms were randomly selected. All ten farms differed in terms of location, size, crop patterns and management strategies. Prices for the respective crops grown across the ten farms were derived on a farm-level. Prices and costs were then deflated by applying the Paasche equation with consumer price index and cost index used as deflators (CBS, 2002).

Yields were detrended by means of a time series model, mostly linear modelling but where heteroskedasticity existed the multiplicative variation was applied. Kobzar (2006) went on to identify some optimization constraints, which are assumed normative based on literature. The constraints referred to land allocation among the different crops in terms of restrictions regarding land rotations in the Netherlands along with labour constraints, both fixed and seasonal labour.

To analyse the results, Kobzar (2006) set alternative gross margin parameters using different forms of modelling to establish each parameter. The expected gross margins for each farm were calculated based on expected yields, prices and cost multiplied by the observed area of each respective farm. The value is a regressed value derived from the Generalized Least Square (GLS) procedure.

The next parameter in the study was the maximum expected gross margin (GM*max*$_{nT}$) for farm *n* in Year *T*. This value was derived by Linear Programming (LP) using the expected values of the gross margin components in year *T* (Kobzar, 2006).

$$GMmax_{nT} = max\left\{\sum_{q=1}^{Q} A_{qnT}(\hat{Y}_{qnT}\hat{P}_{qnT} - \hat{C}_{qnT})\right\}$$

Where *A* represents the optimized activity level of crop *q* on farm *n* in year *T*. $\hat{Y}_{qnT}, \hat{P}_{qnT}, \hat{C}_{qnT}$ is the expected yield, price and variable cost respectively of crop *q* on farm *n* in year *T*.

The risk minimizing parameter (GMmin$_{nT}$) is the expected gross margin when standard deviation is minimised. Quadratic Risk Programming (QRP) is the method used to derive such results, under the condition that all land is used for production. This optimization echoes the best crop arrangement for farmers who are averse to risk (i.e. minimizing stand deviation of total gross margin) (Kobzar, 2006).

$$SD(GM_{nT}) = min\left\{\sum_{q_i,q_j=1}^{Q_i,Q_j} A'_{qnT}\, M_{nT}(q_i, q_j)A_{qnT}\right\}, i \neq j$$

$$subject\ to \qquad GM_{nT} = \sum_{q=i}^{j} A_{qnT}\, G\widehat{M}_{qnT}, \quad GM_{nT}\ \ varied$$

$$b_{qnT} = z_{qnT}\, A_{qnT}$$

$$A_{qnT} \geq 0$$

SD(GM$_{nT}$) is the standard deviation of total gross margin in year *T* on farm *n*; *M$_{nT}$(q$_i$,q$_j$)* is a variance-covariance matrix of the gross margins of the different crops grown (e.g. i and j); *b$_{qnT}$* represents the resource stocks available; z$_{qnT}$ is the amount of resource used (technical coefficient) by crop *q* on farm *n* at year *T*; lastly, $G\widehat{M}_{qnT}$ is the expected gross margin of crop *q* on farm *n* in year *T*.

The linear programming model to generate GMmax$_{nT}$ and the quadratic risk programming model to generate GMmin$_{nT}$ are run through an algebraic software called GAMS (General Algebraic Modelling System). As already mentioned, the results from GMmax$_{nT}$ represent the optimal plan for a decision-maker neutral to risk, whereas GMmin$_{nT}$ provides an optimization plan for risk-averse decision-makers.

Kobzar (2006) took the analysis a step further when he used $GMmax_{nT}$ and $GMmin_{nT}$ to approximate a risk efficiency frontier following a concept known as the risk gradient value (RGV). The value is calculated on a per farm basis, depicting the gradient of the efficiency line. The RGV therefore represents the farm-specific trade-off between expected gross margin and standard deviation (Kobzar, 2006).

$$RGV_{nT} = \frac{\Delta GM_{nT}}{\Delta SD(GM_{nT})} = \frac{GMmax_{nT} - GMmin_{nT}}{SD(GMmax_{nT}) - SD(GMmin_{nT})}$$

The RGV tells one how much risk (standard deviation) can be avoided at what expense of the return (expected gross margin) i.e., the efficiency of risk management. A higher RGV means that a substantial amount of gross margin is forgone by a single unit reduction in standard deviation (risk). Therefore, the lower the RGV on a specific farm, the more efficient the farm is in terms of risk management and hence diversification strategies.

From the study, Kobzar (2006) was able to not only identify how efficient Dutch farms function in terms of the trade-off between risk and return. Moreover, the study depicted the nature of each of the crops grown in the Netherlands in terms of their contribution to an optimal portfolio.

The optimization results revealed some crop production strategies with similar characteristics on all the farms. Sugar beet was found to be a crop with great potential for inclusion in an optimized diversification portfolio. It possesses relatively high and very stable (low variance) gross margins. On the other hand, barley was found to have the lowest gross margin, but its production was extremely constant and stable, making it an attractive option in the portfolio of a risk-averse farmer (Kobzar, 2006).

The remaining crops showed signs of varying gross margins across the years of the study period, making them relatively risky crops for production. The results from the study recognized how farmers can use risky tuberous production to push the expected return figure but at the same time assure stability through cereal production, which has a low variance. The accuracy of the results is often a reflection of the number of limitations in the study and/or model used.

Under the programming models used by Kobzar (2006), the shortcomings identified in the study were rather limited. One of which is that the it was assumed that the supply of hired labour was constant throughout the year, which due to the influx of foreign labour into the Dutch labour market is not too unrealistic in fact (Kobzar, 2006). The last notable limitation in the study was the use of historical data and the doubts surrounding its relevance due to differences in the data and outcomes of interest for the study.

However, given the magnitude of the study and the complexity of the QRP and LP models, these limitations can be manipulated and are rather insignificant.

Bringing the focus closer to Malawi, Maleka (1993) performed a study in Zambia with the objective of determining the optimal cropping pattern in a rural area called Gwembe Valley. Here, the local government encourages crop production in the area but ignores the consideration of risks associated with agriculture in the area. Given the highly erratic nature of rainfall in the area, it is critical for risk to be a part of a discussion of the optimal cropping pattern for the area.

Maleka (1993) used a simplification of quadratic risk programming known as Minimization of Total Absolute Deviation model (MOTAD). A MOTAD model replaces the variance-covariance matrix found in quadratic programming with mean absolute deviations. Such a replacement to the model means that it becomes linear in nature rather than quadratic.

More specifically, Maleka (1993) used a variant of MOTAD known as Target-MOTAD, which measures risk as absolute deviations from a prespecified (target) level of income (Tauer, 1983). The relevance for using Target MOTAD as oppose to normal MOTAD modelling is that mean income levels do not necessarily mean they are sufficient to satisfy basic needs (Maleka, 1993). Therefore, Target MOTAD allows for the risks that impose on meeting basic needs for household food security to be captured.

The general specification of the Target MOTAD model was to maximise the expected value of the gross margin from cropping (revenue), subject to several constraints. Seven crops were identified to maximise the gross margins thereof, namely maize, cotton, sunflower, soyabeans, sorghum, rice and wheat. The study grouped the Gwembe Valley land into 5 zones and estimated the cultivable hectarage of each zone based on information from the local Department of Agriculture and Rural Development Studies Bureau (Scudder, 1962) .

The objective function of the study can be expressed mathematically as:

$$MAXIMIZE\ Z = \sum_{j=1}^{5}\sum_{q=1}^{7}\left[E(C_{jq})(X_{jq})\right] - \sum_{j=1}^{5}\sum_{q=1}^{7} Ib_{jq}$$

Where $\left[E(C_{jq})(X_{jq})\right]$ is the expected gross margin from crop *q* in zone *j* grown under rainfed conditions; *j* represents zones 1 to 5; *q* represents the seven crops identified already; b_{jq} is the amount of cash credit obtained for crop q in zone j; and I is the annual interest charge on the cash credit attained from loan lending institutions (Maleka, 1993).

The specifications of the optimization constraints applicable to the study are as follows:

Land constraint – Let L_j be the amount of arable land available in zone j, a_{jq} is the amount of land to produce one unit of crop q in zone j, and X_{jq} is the number of units of crop q grown in zone j. Then the land constraint is given by:

$$\sum_{j=1}^{5}\sum_{q=1}^{7} a_{jq}X_{jq} \leq L_j$$

Labour constraint – Let A_{jq} reflect the amount of labour required in man-days to produce one hectare of crop q in zone j under rainfed conditions, and l_j is the amount of labour man-days available in zone j. The constraint can be expressed as:

$$\sum_{j=1}^{5}\sum_{q=1}^{7} A_{jq}X_{jq} \leq l_j$$

Credit constraint – Q_{jq} is the amount of cash capital needed to produce one unit of crop q in zone j, b_{jq} represents the amount of cash capital borrowed during the cropping season, and M_{jq} reflects the amount of cash available at the start of the season in zone j for crop q. Then:

$$\sum_{j=1}^{5}\sum_{q=1}^{7} Q_{jq}X_{jq} - \sum_{j=1}^{5}\sum_{q=1}^{7} b_{jq} \leq M_{jq}$$

Soil moisture constraint – Let R_{jq} be the amount of rainfall measured in ha-mm in zone j for crop q, and t_{jq} represent in mm per hectare the water requirement for crop q in zone j. The constraint is specified as:

$$\sum_{j=1}^{5}\sum_{q=1}^{7} t_{jq}X_{jq} \leq R_{jq}$$

The next two constraints deal with the risk aspect of the model. They attempt to quantify the levels of risk.

Negative deviation from a prespecified target revenue constraint – Whilst wanting to maximise expected gross margins from various cropping activities, decision-makers are also anxious about their income levels falling below a crucial target (Maleka, 1993). Therefore, the deviations of revenue below this crucial target level reflect one aspect of the decision-maker's risk (Maleka, 1993). Let Y_k be the negative deviations below target revenue levels during the rainy season for the kth state of nature, c_{jq} is the expected revenue per unit of crop q in zone j, and T is the target revenue during the rainy season. Then:

$$\sum_{j=1}^{5}\sum_{q=1}^{7} c_{jq}X_{jq} + Y_k \leq T$$

Sum of negative deviations multiplied by the probabilities of the states of nature constraint – The second feature of a decision-maker's risk perception is that the expected value of total deviation below target revenue identified above should be restricted to a single value (Maleka, 1993). Therefore, the study follows Tauer (1983), who equates the sum of the product of the deviation associated with a specific state of nature and the probabilities of each stat of nature respectively. Resulting in:

$$\sum_{k=1}^{5} p_k Y_k = \beta$$

Where p_k is the probability of state of nature k and β is the risk parameter representing the sum of expected deviations below the target revenue.

Given the sparsity of data in the area, the figures of the expected gross margins for each crop in each zone were estimated under the various states of nature by the farmers. The values were then validated by agricultural officers in the area. An assumption that each of the seven crops has an equal chance of competing for land means that the coefficient of the land constraint takes a value of one (Maleka, 1993).

Data for the labour and capital constraints is obtained from field surveys, whilst the soil moisture constraint is derived from the Nanga National Irrigation report (1985). During a field survey in the Gwembe Valley, the empirical estimation of the target revenue was discussed with farmers, agricultural experts, and policy makers. A figure of K20 million was deemed to be the target revenue. The risk parameter (β) was assigned the value of K4 million. This figure was validated on the foundation that farmers in the area usually tolerate losses, which amount to one-fifth percent of the target revenue (Maleka, 1993).

The results of the Target MOTAD model under the given formulations and parameters shows that in total across all five zones, sorghum is allocated 45614ha, rice 30070 and soyabeans 43570 ha, respectively. A detailed breakdown of the land allocation according to the zones was also given in the study to give a comparison of the efficiency results with the current cropping patterns. The expected gross margin from the model solution reaches K18 million with K1.9 million of cash capital required to finance such a cropping pattern (Maleka, 1993).

The already evident existence of diversification amongst the Gwembe Valley farmers shows they are risk-averse decision-makers. Despite the similarity of results and the current cropping pattern, some differences were also found. Maize, sunflower and cotton are not allocated land in the optimal results derived from the model solution (Maleka, 1993). The study predicts the exclusion of maize to be attributable to its higher requirement to fertiliser and pesticides, and therefore making it more expensive to produce than rice and soybeans which require less inputs.

Maleka (1993) added a sensitivity analysis to test the validity of the results, which showed that the model was extremely sensitive to changes in cost of credit and cost of taking risk. The model tended to allocate more land towards sorghum production as cost of credit and risk taking increased. This was testament to the drought-resistant nature of sorghum in the study area. The study found that an implication of the absence of maize, cotton and sunflower on household food security would mean that these crops would need to be imported to the study area to meet household food security (Maleka, 1993). However, a limitation to the model used in this study must be noted; the sparsity of data in the study area and the resultant estimation and use of averages, limits the accuracy of the results from the chosen modelling method.

2.6 Quadratic Risk Programming (QRP) approach to diversified agriculture in Malawi

Sparsity of data often proves to be a challenge amongst smallholder farmers, particularly in a rural country like Malawi. Msusa (2007) took on the challenges associated with collecting data to try and analyse the production efficiency of smallholder farmers in the Dowa region of Malawi. The study was able to access input data regarding yields and costs, as well as land-holding size, technologies and labour availability from farmers belonging to a Chiyambi Producers and Marketing Cooperative. The data set followed the 2003-2005 period.

Data referring to labour requirements were estimated from research by Johnson (1982) and Alwang & Siegel (1999). Costs and prices were derived from national prices during 2003-2006; the nominal prices were then deflated using the consumer price index and the cost index for the year 2000. Chiyambi farmers in the Dowa region were then classified into four homogeneous groups according to their productivity. Each farmer's productivity was measured against the mean productivity and standard deviation from the farmer group (Msusa, 2007). Following the 'crash' of the tobacco prices, Msusa (2007) focused the inclusion of farms in his study to only those that produce some amount of tobacco in their cropping patterns, be it specializing in tobacco production or simply part of their diversification strategy.

To estimate the total income of each crop, estimated prices of the respective crops from the year 2006 to 2016 were multiplied by the average yield of the crop during 2003 to 2005 (the observed years) (Msusa, 2007). The constant average cost of each crop was then subtracted from the total income of each crop. This procedure was followed for a representative farm from each of the four groups. The resultant profit coefficients of four crops namely tobacco, maize, groundnuts and Phaseolus beans was obtained for use in the model (Msusa, 2007).

The study ran the profit coefficients across the observed years through a QRP model to generate an efficient expected return vs risk frontier (E,V) of farm plans. As is the nature of the QRP model, a variance-covariance matrix of profit coefficients is required. The variance of profit coefficients was given by:

$$x^t S x \;=\; [x_1 \cdots x_k] \begin{bmatrix} \sigma_{11} & \cdots & \sigma_{1k} \\ \vdots & \ddots & \vdots \\ \sigma_{k1} & \cdots & \sigma_{kk} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_k \end{bmatrix}$$

Where x is a vector of production activity levels; S is a variance-covariance matrix of profit coefficients; σ_j is the variance of profit coefficient of crop j; and σ_{ij} the covariance of the profit coefficient ($i \neq j$). Msusa (2007) made note of two significant aspects when analysing the relationships between profit coefficients: 1) A combination of crops that shows a negative covariation of income will normally show a more stable aggregate return than the return from specialized farming activities (Msusa, 2007). 2) A crop that possesses risky attributes in terms of its variance in returns, may still be attractive if its returns show a negative covariation with other crops in the farm plan (Hazell & Norton, 1986).

As mentioned earlier, the efficient E,V farm plan can either be obtained by maximising revenue while varying risk (variance) over its feasible range, or by minimizing risk whilst varying revenue over its feasible range (Anderson *et al.,* 2015). This study chooses the latter, to minimise variance across the possible levels of expected income, given by the formula:

$$\text{Minimise } x^{t}Sx$$

$$\text{Subject to: } Ax \leq \dot{r} \quad x \geq 0$$

$$\text{Where } A = \begin{bmatrix} 1 & \cdots & 1 \\ \mathrm{l}_{1J} & \cdots & \mathrm{l}_{kJ} \\ \vdots & \ddots & \vdots \\ \mathrm{l}_{1D} & \cdots & \mathrm{l}_{kD} \end{bmatrix} \quad \dot{\mathrm{r}} = \begin{bmatrix} \bar{\alpha} \\ \bar{\mathrm{l}}_{J} \\ \vdots \\ \bar{\mathrm{l}}_{D} \end{bmatrix}$$

A is an input-output matrix of coefficients of production, l_{km} is the labour resource requirement for each month, $\dot{r}$ is the vector of resource availability, $\bar{\alpha}$ is the land resource constraint, and l_M is the labour resource constraint for each month. The model is then run to identify the combination of crops that has the least variance for a given level of income.

Figure 2.3 shows the efficient expected return vs variance frontier generated using QRP for one of the four groups used in the study. The figure shows the current land use and the corresponding expected income level. The model generates the efficient frontier which, evident on Figure 2.3 below, shows the optimal land allocation point at the same expected income level but with a much lower level of variance.

Furthermore, the model reveals the cropping pattern responsible for the optimal allocation point. The results for each of the four groups revealed slightly different solutions but all showed that the actual current land use patterns were not at the optimal combinations, which could achieve the same level of income but at lower levels of risk (Msusa, 2007).

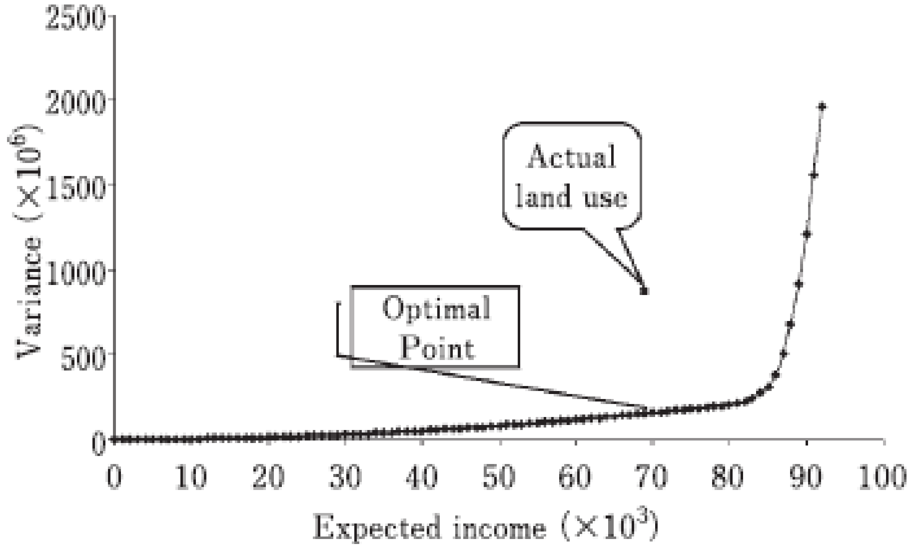

Figure 2.3 E,V frontier for representative farm

Source: Msusa (2007).

A constant found across all four groups was that the average profit coefficient was lowest for tobacco compared to the other crops in the study. Tobacco and beans also showed the highest variance across all four groups, which indicated they were the riskiest crops. Groundnuts proved to be the least risky crop with the lowest variance in all groups studied. Furthermore, groundnuts covaried negatively with both maize and tobacco, which according to the significant aspects made by Msusa (2007) when analysing relationships between profit coefficients, is a rather attractive characteristic. Following this, the results from each group indicate a major increase in land allocation to groundnuts in combination with decreasing maize and tobacco allocations, with particularly significant reductions in tobacco production (Msusa, 2007).

Msusa (2007) characterised each crop according to its risk and return attributes. Tobacco had the lowest profit coefficient, further exemplified by having the highest variance, meaning its land allocation should be reduced to manage risk optimally. Maize has a higher profit coefficient but also a higher variance than groundnuts, which indicates that, although not in as dramatic fashion as tobacco, maize land allocation should be reduced. Beans also showed a rather high variance together with a positive covariation with most of the crops, suggesting the aggregated returns of the crop are unstable. Hence, the model also indicates a reduction in land allocation away from beans. The results favour the allocation of land to groundnuts, testament to its high profit coefficient and lower variance (Msusa, 2007).

Limitations to the study include the relevance of the data used to derive the model. Given the use of average yields derived from the observed period (2003 to 2005), which is multiplied by estimated prices for 2006 to 2016 to determine expected income, and then further diluted by a constant average cost for each crop – leads to the accuracy of the resultant coefficients being questioned. However, the study makes a recommendation for further studies to use a more advanced method to generate the time series data necessary for the QRP model. The study also makes some recommendations for appropriate agricultural input and output policies catered by suitable extension services to benefit smallholder farmers.

2.7 Summary

The study by Msusa (2007) using quadratic risk programming (QRP) reveals an optimal cropping pattern for smallholder farmers looking to diversify. The study is limited by only four crops and the inclusion of tobacco is compulsory by farmers used in the study. The nature of the data and statistics generated in the study are weakened by assumptions such as 'fixed average cost per crop' and constant yield assumptions multiplied by estimated prices. Looking past the troubles of input data for the study, the QRP model itself proved to be a worthy option to generate an efficient farm plan for smallholder farmers in Malawi. Such a farm plan is deemed necessary in light of the risk – return trade-off faced by smallholder farmers and can be portrayed graphically on a E,V frontier. Mango et al. (2018) proved that diversification has a positive influence on household food security in Malawi. Household size, access to extension services, distance to market and infrastructure were identified as key determinants which prompted a farmer's decision to diversify (Kankwaba et al, 2013). The shortfalls in the literature reviewed above was the inability to provide a comprehensive optimisation model applicable to distinguished smallholder farm categories as well as relevant, practical answers as to how one should diversify within these categories.

Chapter 3: Study Methodology

3.1 Introduction

Following the evolution of the trade-off scenario and the review of optimisation studies referring to diversified agriculture, particularly smallholder agriculture, various mathematical programming models proved to have the capacity to satisfy such a topic. Linear programming, as used in studies by Maleka (1993) and Kobzar (2006), provided a combination of agricultural activities which would maximise revenue on a farming enterprise. Linear programming assumes a linear relationship amongst constraints and activities, whilst measuring the risk of an activity as the variation of a gross margin from a mean gross margin of that respective activity.

From the theoretical discussion in Chapter 2, linear programming's more complex counterpart, quadratic risk programming (QRP), also offered optimisation solutions as seen in studies by Kobzar (2006) and Msusa (2007). QRP differs to its linear cousin in that the cost of risk taking is defined in terms of a variance – covariance return matrix of respective farming activity gross margins rather than mean absolute deviations (Maleka, 1993). The nature of diversification involves the relationship between two or more activities, particularly in agriculture. Therefore, the use of a variance-covariance matrix to capture the risk of the respective activities more accurately in a production portfolio is essential for an optimisation problem.

Chapter 2 highlighted the use of quadratic risk programming (QRP) to uncover key diversification insights in smallholder agriculture. The same study by Msusa (2007) concluded with suggestions that an updated and more 'data accurate' optimisation study was necessary for diversified smallholder farmers in Malawi. The following chapter begins with a brief introduction of mathematical programming and the commonly used linear programming model. Following this, the chapter provides a theoretical background and explanation of quadratic risk programming – which is the methodology implemented selectively in this study. From Section 3.5, the Chapter then goes on to provide a detailed discussion of the practical application of the methodology and the acquired data to simulate such an approach. Section 3.8 concludes the Chapter.

3.2 Mathematical programming

The term *mathematical programming (MP)* is used to label a family of optimisation methods (Anderson *et al.,* 2015). In recent years, mathematical programming has evolved into a widely used tool in planning, decision-making, and economic analysis in the agricultural world. Its extensive importance and use has been facilitated by major advances in computing technology and software capable of incorporating the institutional and economic farm reality into the models (Hazell & Norton, 1986). As the software has evolved, so too has the complexity of the mathematical programming models capable of being solved. However, all the available algorithms are not yet quite capable of reliably solving all MP models, particularly as the complexity of the model increases with the inclusion of concepts such as risk and uncertainty. However, historically Hazell and Norton (1986) have found that models have the ability to incorporate high levels of micro-level data for the analysis of policy issues relating to pricing, employment, investment decisions, comparative advantage and significant to this study and risk analysis.

3.2.1 Linear Programming

The first to be applied and the simplest form of mathematical programming is *linear programming (LP).* The nature of LP models is specified with respect to maximising or minimising a linear objective function subject to a set of linear constraints (Anderson *et al.,* 2015). In other words, linear programming is used in farm planning to identify the combination of activities that will maximise or minimise an objective, such as maximising expected profit or minimising the cost subject to a set of resources and other constraints.

The simple nature of an LP model means that there are several algorithms capable of reliably solving such optimisation models. From a maximisation perspective, linear constraints such as resource availability together with accounting and institutional constraints, form a convex set of constraints with a finite number of feasible solutions.

Each constraint defines a linear 'boundary' of the feasible set and together they form a convex curve with respect to the origin. The objective function, which too is linear, is a plane cutting through the convex set demarcated by the linear constraints. Every point on the plane has the same value of objective function but it is only the points on the plane within the convex set that are feasible.

The main limitation of LP is that the real world is seldom linear, however with a little ingenuity, linearly defined problems can be approximated reasonably well at the expense of accuracy (Anderson *et al.*, 2015). When applied to agriculture, linear programming is a method of determining the profit maximising combination of farming activities that are feasible given a set of fixed farm constraints (Hazell & Norton, 1986).

Such modelling would seem adequate to answer the questions of optimising diversification strategies for a study in Malawi. However, the introduction of risk and risk aversion is met with a few limitations when applied to linear programming models. The obvious problem which stands out when using LP for risk analysis is the linear objective function, since risk aversion generally implies optimisation following a non-linear utility function (Anderson *et al.*, 2015).

Early applications of the LP models in farm planning assumed profit maximising behaviour, no growth (i.e. a single period planning horizon), and no uncertainty with regard to price, yield and other elements in the planning environment (Hazell & Norton, 1986). The assumptions and properties of linear programming would become inaccurate or simply invalid with the inclusion of a non-linear utility curve. Fortunately, there are mathematical programming models which can solve more complex problems with non-linear objective functions, subject to a set of linear constraints. In such a case, the non-linear objective function, which is often the case when maximising expected utility under risk aversion, is convex to the feasible set formed by the constraint boundary (Anderson *et al.*, 2015). The evolution of algorithms and computer software capable of dealing with the complexity of quadratic, non-linear programming models have rendered many of the earlier LP models outdated.

3.3 Mean-Variance or *E, V Efficiency* analysis

When implementing an economic analysis derived based on a decision-maker's preference, a utility function is the subsequent instrument. However, when dealing with a large and diverse sample of decision-makers, it is unknown what each person's preferences entail. As a result, an efficiency frontier forms the pinnacle of the analysis.

3.3.1 Efficient Expected income (E) vs Variance (V) frontier

Perhaps the most important outcome of an optimisation model is the interpretation and analysis of the results, particularly when individual preferences are unknown. Such an analysis evolved from the ground-breaking Markowitz (1952) Portfolio Frontier model, which forms the basis of the E, V efficiency analysis.

The efficient expected income-variance criterion is a useful guide during the decision analysis process, which sees the direct comparison and relationship between 'risk and return'. As mentioned earlier, a portfolio consists of a compilation of assets or in this case farming activities, which carry an expected return. The expected income of a portfolio marks the return element whilst the variance of the portfolio is used to quantify risk.

The level of risk perceived to be acceptable by a farmer will vary in accordance with his/her beliefs and preferences. Therefore, in the case where such preferences are unknown and hence the utility function is also unidentified, then certain assumptions about a farmer's choices are necessary. Furthermore, in agriculture it is often required to analyse and develop recommendations for hundreds if not thousands of farmers usually in a particular target group, making the validity of assumptions even more necessary.

3.3.2 Assumptions of expected income-variance criterion

The first assumption of the E,V criterion is one which assumes that a farmer's preferences among alternative farming portfolios are based on the expected income of each portfolio and the attached variance of the portfolio (Hazell & Norton, 1986). The assumption of the E,V efficiency rule is that for two portfolios, A and B, if the expected income of A is greater than the expected income of B (i.e. E[A] > E[B]) and the variance of A is equal to or less than the variance of B (Var[A] <= Var[B]), then portfolio A is preferred to portfolio B (Williamson, Luckert & Hauer, 2011; Anderson *et al*., 2015). The third property of E,V efficiency is that the shape of the efficiency frontier is a concave shape with respect to the origin under the assumption that decision-makers are risk averse and portfolio returns are normally distributed (Hazell & Norton, 1986). In addition to the assumption of subjective identical probability distributions, it is also assumed that a decision-makers' utility function is quadratic in nature (Anderson *et al*., 2015).

3.3.3 Limitations

The initial assumption of subjective identical probability distributions is a computational adaption from previous ideas, which proposed a quadratic utility function for income with returns that were not normally distributed (Hazell & Norton, 1986; Williamson, Luckert & Hauer, 2011). Since normal distributions are regarded as the exception rather than the rule in decision analysis, and a quadratic utility function implies the improbable scenario that absolute risk aversion increases in conjunction with the level of return, then the E,V efficiency criterion is best regarded approximation rule (Anderson *et al.*, 2015).

3.3.4 Advantages

The unknown decision-maker's preferences and the utility functions have brought its limitations. Importantly, the computational variations and assumptions added to the data which derive from the E, V efficiency frontier, offset the theoretical limitations which may exist. Many of these theoretical confines were labelled as being untenable by many theorists (Pratt, 1964; Hazell and Norton, 1986).

The E,V efficiency frontier approach allows for the evaluation of portfolios with only mean and return variance distributions (Williamson *et al.*, 2011). This advantage largely explains the popularity of the E,V approach amongst agricultural economists to provide partial ordering of alternatives on the E,V frontier which are deemed efficient (Anderson *et al.,* 2015). In addition to the convenience of the E, V approach when the utility function is unattainable, several financial analysts regard it as the foundation of modern portfolio theory. The strategy generates an optimal portfolio combination with a feasible trade-off between the maximum possible return/profit and the corresponding minimum level of risk required to achieve that return.

3.4 Quadratic risk programming (QRP)

Quadratic risk programming (QRP) in agriculture can be used to generate the efficient E, V set of farm plans. The model takes the foundation of linear programming and builds upon it with the addition and adaption of features to better incorporate risk. As this study is concerned with using diversification (a portfolio of farming activities) as a tool to minimise risk, the use of QRP is paramount. This is enabled by the inclusion of a variance-covariance matrix in the model. This matrix allows for an analysis of portfolios rather than individual activities.

The main rationale for looking at returns and variances of the portfolio rather than individual activities, is that the interrelationship between the individual activities often influences the level of risk (or variance) of the portfolio (Williamson *et al.*, 2011). In farming, it is often the case that the variance associated with a portfolio of activities is less than the weighted average of the variances of the individual activities (Zerbe & Dively, 1994). Further technicalities of the interrelationships within a portfolio and their effect on the total variance will be discussed later in this thesis.

The QRP model can be formulated in several ways. If the decision-maker's risk aversion parameter is known, then one way to formulate the model would be to maximise the certainty equivalent (CE):

$$CE = E - 0.5r_aV$$

where E is the expected income, r_a is the risk aversion coefficient and V is the variance of income (Anderson *et al.,* 2015). However, as is the case here, all that is assumed is that the decision-maker is risk averse and hence the r_a coefficient is unknown. Therefore, it is necessary to generate the whole E, V frontier. The formulation of the model to generate the frontier can take one of two forms: either maximising E (portfolio expected return/profit) while varying V (portfolio variance/risk) over its feasible range, or by minimizing V while varying E parametrically over its feasible range.

The feasible range is determined by the available resource constraints. Although both forms will generate the same E, V efficiency frontier, this study makes use of the latter formulation with the objective function to minimise V. This can be formalised as follows:

$$minimise\ V = x'Qx$$

subject to

$$Ax \leq b$$

$$E = cx - f, with\ E\ varied\ parametrically\ over\ its\ feasible\ range$$

$$x \geq 0$$

where *x'* is adjustable variables which represent activity levels, *Q* is a variance–covariance matrix for activity net returns per unit, *A* is the resource use per unit of activity and *b* is the resource constraint. *E* is expected return, *c* is net revenue per activity and *f* is fixed costs (Anderson *et al.,* 2015).

The benefit of this formulation is that the non-linear element is restricted to the objective function, which means the feasible set remains convex and difficulties in solving the optimal solution are minimised (Anderson *et al.*, 2015). The inclusion of the variance-covariance matrix is fundamental for efficient diversification within a portfolio as an instrument for hedging against risk (Markowitz, 1959).

Combinations of activities whose returns covary negatively will normally have a more stable aggregate return than the return from more specialized activities (Kobzar, van Asseldonk & Huirne, 2002). Furthermore, an activity with a high variance of returns and therefore deemed to be risky, may still prove attractive in a portfolio if its returns are negatively covaried with the returns of other activities in the portfolio (Hazell & Norton, 1986). As the objective function states, it is required to minimise the variance-covariance component for each possible level of expected income (E) whilst still retaining feasibility with respect to the available resource constraints (Kobzar *et al.*, 2002).

In this case, the aim of the model is not to maximise income but rather minimise risk. Therefore, the income (E) must be treated like a constant parameter. There are two ways to determine the value of the fixed income parameter, either by farmers' experiences from year to year or through mathematical programming (Kobzar *et al.*, 2002). Using linear programming, the maximum expected income given the respective constraints, can be derived. This maximum income constant is determined without risk optimisation and therefore will have a high variance (risk) factor attached to it. This figure is the maximum possible return obtainable by the model, exploiting all possible resources and constraints.

To check the validity of this figure, the model can be run with an E value above the derived income level and the results should generate an infeasible solution, showing that derived figure is indeed the absolute maximum expected income level attainable (Kobzar *et al.*, 2002). From here, the model can be rerun by parametrically changing the value of the expected income (E) by a prespecified amount.

For example, if the maximum income level derived by linear programming proved to be R250 000, then the model can be programmed to run by reducing the E value in increments of say R25 000. The model will reach a level where it suggests not all activities, resources and constraints are used to their full capacity to achieve the stated expected income level. By using quadratic risk programming and introducing the variance-covariance element to the model, it produces the portfolio mix which minimises the variance needed to achieve the respective income levels. The parametrized expected income levels are plotted against the minimum level of variance required to achieve that income to display the E, V efficiency frontier.

Given the non-linear nature of the objective function, the model must be solved by a quadratic programming algorithm (Hazell & Norton, 1986). The software commonly used to run the model and implemented in this study is GAMS – the General Algebraic Modelling System.

3.5 QRP application to southern Malawi

The next step in this study's methodology is to put the theoretical foundation of quadratic risk programming into practical application. A study area and target group formulate the basis for the practical application which then requires detailed crop data from the specific target group.

As mentioned in the description of the study area, southern Malawi is host to a vast portion of the country's population of which an even bigger proportion are reliant on smallholder farming as their source of livelihood. Smallholder farmers in Malawi are characterized predominantly by their poor nature and consequently their inability to invest in the necessary inputs to realise the most potential from their small piece of land. The average farm size in southern Malawi barely exceeds half a hectare and if a household is so reliant on this small piece of land it makes it crucial that the farmers optimise their farming activities to the best of their ability.

The small farm sizes together with the dominant reliance on agriculture among households, means that there are copious amounts of smallholder farms tightly packed in the overpopulated southern region of Malawi. It is these farmers, and the large proportion of the population that they represent, that are faced with poverty on a day-to-day basis, which this study focuses on.

Bearing the consequences of a poor harvest due to drought, floods or even economic crisis would be catastrophic to these destitute farmers. Therefore, it becomes crucial that these smallholder farmers diversify their farming activities in such a way to optimise their income but at the same time minimise the risk they are exposed to. None of the target population belong to any contract and their production decisions are based purely on their preferences.

As can be expected within such a large study population, there are variations in the nature of the farmers, be it in the form of farm size or financial capacities which a farmer possesses. This study also identifies the use of inorganic fertiliser or not, as an influential difference in the study population. This study recognises and accommodates the fact that these structural differences may have a significant effect on the optimisation strategy chosen by farmers.

Therefore, the study divides the target population into three main groups based on their farm size as small, medium and large farms. Small farms are those smaller than two acres in size. Medium farms range in size between two and four acres. While large farms are between four and six acres. It is important to note that the farm size which categorizes the group a farmer falls into, is referring to his/her cultivatable land size.

To address the discrepancies regarding the capabilities of fertiliser use, each group of farmers (small, medium, and large) was then further split into those that apply inorganic fertiliser and those that do not, resulting in six scenarios. There are other disparities in the target population such as variations in the amount of farm saved seed, but these are deemed to play a less influential role when compared to land size and fertiliser use. Although it perhaps dampens the accuracy of the input data for the study, it would be highly complex to run through the paramount number of disparities that may exist within the target population. Therefore, the study caters for six scenarios deemed to be the most pivotal and accurate representation of the study population.

3.6 Data Collection

3.6.1 Source of data

Only a handful of smallholder farmers are fortunate enough to have attended and finished secondary education in Malawi, this coupled with the small scale of operations these farmers function on, mean that very few keep any financial records relating to their farming activities. With this comes challenges when trying to perform an economic analysis where no or few records are kept. After the review of quadratic risk programming in chapter 3, it was seen that the profit coefficients for each farming activity were necessary for at least a three-year historical basis – to capture the variation in profits to run the model accurately. Fortunately, there are a few companies in Malawi who work with smallholder farmers, particularly providing them with access to inputs and in some cases access to a market. Following this, data for this study was predominantly sourced from these companies who have a particular focus on the smallholder farmers in southern Malawi. The two key sources of data were One Acre Fund and the Agora branch of Farmers World limited.

3.6.2 One Acre Fund

One Acre Fund is non-profit social enterprise who works with smallholder farmers in various African states to help these farmers grow their way out of hunger and develop lasting channels to prosperity (OneAcreFund, 2020). They achieve this by providing proven tools, inputs, as well as financing options to put farmers first in their approach to tackle poverty in sub-Saharan Africa. The Malawi branch of One Acre Fund has its head office in Zomba, a city situated in southern Malawi where they serve the smallholder farmers in the southern region of the country. The data obtained from One Acre Fund is comprised of input cost surveys conducted on an annual basis from the year 2017 until the year 2019. Although the data is made up from surveys targeted at those farmers on the One Acre Fund scheme, the survey also extends its reach to ordinary farmers surrounding the One Acre Fund farmers.

These farmers are labelled 'controls' as to allow for analysts to visualise a difference between their One Acre Fund farmers and those surrounding them to justify the impact of their scheme. This study recognises that farmers on schemes like those of One Acre Fund may reveal above-average returns when compared to farmers who do not have access to finance, inputs and an established market. Therefore, the inclusion of farmers on the scheme may jeopardise the accuracy of this study which targets the more 'ordinary' Malawian smallholder farmer. Following this, the study makes use of the control data obtained from the One Acre Fund surveys.

The filtered and cleaned data left a sample size of at least two hundred smallholder farmers in each of the three years' worth of input cost surveys. The useful figures attained from the surveys related to cultivatable land size, labour input costs, seed costs, fertiliser costs and yield data for the respective crops grown. More detail of the specific crops and their corresponding figures will follow shortly.

3.6.3 Agora Limited

Whilst the focus of Agora Limited is to offer fertiliser and other agricultural inputs through their one hundred plus stores nationwide, they also support Malawian farmers with extension services through their Farm Services Unit (FSU). The FSU provides farmers with practical and technical farming assistance, aiding farmers in achieving highest possible yields following the guidance from the FSU for the right choice and application of inputs (AgoraLtd, 2020) The focus for this study lies on the Agora Limited company specifically, as they operate the services in the southern part of the country.

Like the data collected by One Acre Fund, the FSU division of Agora conducts annual surveys of smallholder farmers in southern Malawi. Again, once the data has been filtered and cleaned to limit ambiguity in the study, the sample size remains consistently high (above two hundred farmers for each year). Although the input data is not as comprehensive as that provided by One Acre Fund, the Agora surveys provide a more complex breakdown of the output data pertaining to yields, prices and cultivated areas for each specific crop. A distinction is also made in the survey for farmers who utilise fertiliser and those who do not, allowing for an accurate integration into the desired models.

After filtering the data from the two main sources to standardise the sets in terms of land size and fertilise use, it allowed for the integration of the data sets without jeopardising the accuracy of the study. The comprehensive output data from Agora limited complimented the detailed input costs attained from One Acre Fund to create a model for each of the six scenarios targeted in this study. Details about the data formulated and inputted into the model are provided on a crop-by-crop basis in the next section.

3.6.4 Literature sources

Although comprehensive and accurate, there are a few gaps in the data sets compiled from the two main sources above - which need to be filled to complete this study. Where possible, literature reviews were able to fill some of the gaps and provide accurate readings which could be incorporated into the models. For example, labour costs from the two main sources for this study are only relevant to maize production. Therefore, instead of assuming a constant labour allocation across all the crops, crop-specific data was taken from a case study by ICLARM & GTZ (1991) on Malawi - which provides crucial figures relating to the labour requirements of specific crops in several districts in southern Malawi. Although it may seem the study might be old and outdated, agricultural practices have seen little development or change with regards to labour inputs since the study was done, particularly among the smallholder farmers.

3.6.5 Personal interviews

Where no other studies existed to fill some of the other data gaps and to avoid making unnecessary assumptions which would limit the accuracy of this study, a few personal interviews were conducted with smallholder farmers in the study area. The main shortfall needed to be realised from these personal interviews was the constraints, particularly the contentious issue of labour constraints, which existed for each of the six model scenarios. The interviews provided clarification on the daily wages paid for hired labour.

3.7 Time period covered

To generate the risk component of the study, it is crucial to have at least three years' worth of historical data to analyse the variance across the profits of the specific crops. Furthermore, another characteristic special to the quadratic programming model is that the three years of historical data also allow for the covariance of profits among the various crops to be included in the study. The three years of historical data were depicted based on the most recent and readily available data from the two main sources for this study. The time period covered ranges from the 2016/2017 season till the 2018/2019 season. This time period answers the recommendation by Msusa (2007), urging for an updated and more data-accurate study of their optimisation study to be conducted. To provide the reader with context across the time period, the Malawi Kwacha to United States Dollar for the three seasons averaged at 725 MWK/USD in 2017, 729 MWK/USD in 2018, and 734 MWK/USD in 2019 (ExchangeratesUK, 2020).

3.8 Conclusion

Although a more complex version of linear programming and sometimes conceptually challenging, quadratic risk programming is recognised for its ability to accurately rank portfolios along a risk-return frontier (E, V efficiency frontier). The replacement of standard deviation from the mean return in LP with the variance-covariance matrix in quadratic programming, has customized the ability of a QRP model to accurately decipher the level of risk within a portfolio. The quadratic matrix also highlights the ability of diversification to efficiently reduce risk within a portfolio that would otherwise be almost unavoidable in more specialized strategies.

Furthermore, the objective function of a QRP model to minimise variance and hence risk, is in line with the stipulated objectives of this study. The ability of the model to generate an efficient frontier on which solutions can be ranked according to their level of risk means that the output is not confined to a single decision-maker but rather all those decision-makers within the same feasible set confined by the resource constraints. Whilst the assumptions needed for the generation of the E, V efficiency frontier is restrictive, it serves as a popular tool for many agricultural economists dealing with decision analysis, particularly when decision-maker preferences are unknown or unattainable.

The latter sections of this Chapter introduced the practical application of quadratic risk programming to this thesis. The target group as well as the sources of data were identified and discussed in detail. Chapter 4 processes the sourced data into crop specific budgets which allows for compatible integration of the data into the models. The proceeding chapter also analyses the study-specific crops used to fulfil the model requirements and satisfy the study objectives.

Chapter 4: Cropping regimes and data application

4.1 Introduction

Chapter 2 provided a theoretical and practical review of the use of mathematical programming in diversified agriculture as well as a motivation for its application to this study. From an analysis of the mathematical programming strategies used for optimisation, chapter 3 highlighted quadratic risk programming as the most appropriate method to tackle the risk-return frontier in smallholder agriculture in Malawi. Its ability to answer the optimisation feature prominent in all mathematical programming strategies and because it minimises the risk to achieve such optimization makes it crucially attractive. Its application to the study is exemplified when dealing with smallholder farmers in Malawi who lack the financial capacity to absorb the negative effects of risk. Chapter 3 provided a theoretical outline of the quadratic risk programming model which was further detailed with the introduction of the practical component.

Chapter 4 provides a detailed discussion of how the quadratic risk programming model was applied in this study. A key precursor to this discussion involves an analysis of the different cropping systems used in this study and how they were derived to be compatible with the respective models. Due to the variations in crop sample sizes and the nature of the data required for the study, assumptions were necessary to allow for the study to be achieved given data limitations. These assumptions, together with some limitations, are noted in this chapter where necessary. This chapter outlines a stepwise application of the quadratic risk programming model, beginning with the target group through to the generation of results.

4.2 Crop portfolios

The returns on the crop portfolios are calculated on a gross profit margin. After analysing all the collected data from each crop sample, an average turnover for each crop is calculated on a per-acre basis. The same was done for the input costs of each crop to generate crop-specific budgets on a per-acre basis. A distinction in the crop budgets is made between those smallholder farmers who use fertiliser and those who do not.

The crop portfolios analysed in this study are chosen according to their popularity in southern Malawi and the availability of the required data for the respective crop from the data sources. The sample sizes vary year on year in accordance to how many farmers grew which crop in that specific year. To create a model for each farmer would be impractical and unattainable. Therefore, a representative model for each crop is created according to the filtered data analysed across the whole sample population and then manipulated according to either one of the six scenarios. The next section provides a detailed description of each crop used in the study as well as its relevance to the study.

To provide the reader with some background on how the budgets for each crop are compiled, some descriptive statistics for one of the analysed crops (maize) are shown below. These descriptive statistics are an example of how each of the crop budgets is compiled for each respective scenario. Like that of Table 4.1 below, there is a statistical table for each figure inputted into the budgets - be it seed application rate, yield data or any other applicable elements. On top of the rather large volume of descriptive statistics needed for each crop, there is a repetition required for each year. Therefore, for simplicity, the reader is only provided with the descriptive statistics for maize yields but will gain an understanding of how the budgets for each crop are compiled.

Table 4.1 Descriptive statistics for maize yields during the 2017/18 season

2017/18			
Maize yield - fertiliser (Kg/acre)		Maize yield-no fertiliser (Kg/acre)	
Mean	513	Mean	344.5
Standard Error	6.96	Standard Error	12.9
Median	400.1	Median	250.1
Mode	300.1	Mode	200.1
Standard Deviation	344.5	Standard Deviation	259.5
Sample Variance	293 082.8	Sample Variance	166 210.2
Kurtosis	0.44	Kurtosis	1.8
Skewness	1.1	Skewness	1.4
Range	1 450.5	Range	1 350.5
Minimum	50	Minimum	50
Maximum	1 500.5	Maximum	1 400.5
Sum	1 257 467	Sum	137 935.8
Count	2 451	Count	400

The descriptive statistics presented in Table 4.1 show the sample from which the maize yield in 2017/2018 was derived. Important to note from the descriptive statistics, is the high variance and particularly the high value of the skewness figure. A skewness value above +1 or below -1 indicates a data spread with a substantially skewed distribution. Therefore, the study makes use of the median value instead of the mean value. This is done because when data is not normally distributed, the median value is a more accurate representation of the data, as it is less sensitive to a tailed distribution and outliers (Hazell & Norton, 1986). The data is not normally distributed across any of the crops and therefore the median value is the pivotal value in this study.

4.2.1 Maize

As is the case in several African countries, maize is the most important food crop in Malawi and forms a part of the staple diet for the poverty-stricken population. Maize production accounts for as high as 80 percent of the nation's cultivatable land and it is thought that the country's food security is defined by the maize harvests and peoples access to maize (Stevens & Madani, 2016). To ensure food security, it is crucial that smallholders – given their subsistent nature, have sufficient maize production. This study recognises the importance of maize and therefore accommodates its production in the relevant models.

The minimum maize requirement for food is around 129 kilograms per capita for the year (FAO, 2012). This study makes provision for the bulk of this requirement (60 percent) to come from the smallholder's own field. According to the FAO (2018), the average household in Malawi consists of five people, therefore a smallholder farmer needs to produce 387 kilograms of maize. Dependant on the maize yields associated with the six different models, a minimum land constraint allocated to maize production is created.

4.2.1.1 Inputs

Moving on from the minimum maize constraint, the inputs costs of the maize portfolio comprises of seed, labour and fertiliser (where applicable). To aid the struggling smallholder farmers in Malawi, the government has been implementing the Farm Input Subsidy Program (FISP) for a couple of years. The subsidy programme provides access to subsidized agricultural inputs for the smallholder farmers growing the countries staple crop – maize. In addition to the subsidized maize inputs, the FISP is often altered year on year to include other subsidized inputs, for example legume seeds were subsidized in the 2018/2019 season.

4.2.1.2 Seed

A significant configuration of the seed cost for all crops in Malawi and particularly maize, is the use of recycled seed. In the 2016/17 season, the data revealed that 55 percent of the total maize seed used in the sample population was recycled. Most farmers make use of saved seed as a method to cut input costs. The recycled figure remains relatively high across the three years in the study area, contributing to a rather low seed cost.

However, the recycled seed does have its own cost attached to it in the form of an opportunity cost as that seed could have been sold for grain. The study also recognises costs associated with the storage of the recycled maize seed, for example bags to store the maize and fumigation costs. This, together with the purchased seed component - usually bought either through the local market or an agrodealer, make up the input seed cost of the budget.

4.2.1.3 Labour

The data suggests the labour requirement for maize is about 23 man-days per acre, supported by the ICLARM & GTZ (1991) study, which proposes around 22 man-days per acre of maize. Most of these man-days are made up of family labour of which there is no cost attached. As mentioned earlier, the average household size is in surplus of four people. To most of these people, agriculture is their livelihood which means they will prioritise their time in the field looking after their crops in the company of their fellow household members. The use of hired labour for maize production accounts for as little as 20 percent of the required man-days.

4.2.1.4 Fertiliser

Even though the FISP provides fertiliser at an attainable price, there are still farmers who either do not have access to the subsidy programme or still cannot afford the subsidised fertiliser. The unfortunate result for them is a rather insufficient yield. However, for those farmers who can apply fertiliser to their maize, a notable variation in the application rate per acre was seen. After cleaning the outliers, the study arrived at a median application rate slightly below 40kg of fertiliser per acre of maize, this figure saw a slight fluctuation across the three years in the study. As one can expect the use of fertiliser on maize results in a much more respectable yield.

4.2.1.5 Output

With regards to the output data, the prices per kg of maize were farm gate prices announced year on year by the Malawi government. The farm gate prices allow for accurate and relative comparisons to be drawn on an annual basis. The yields of maize recorded is a median value from the study sample after removing obvious outliers in the data set. Again, a distinction is made between the maize yields of farmers who use fertiliser and those who do not. The figures below provide a summary of the maize budgets across the three years for maize production with fertiliser and maize production without.

Table 4.2a Maize budget without fertiliser use

MAIZE No fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	313.6	250.1	300.1
Price (MWK/Kg)	170	150	180
Turnover (MWK/acre)	53 313.7	37 513.1	54 018.9
Costs (MWK/acre)	10 342	9 575.6	12 065.3
Seed (MWK/acre)	3 740.3	2 670.9	3 678.9
Labour(MWK/acre)	6 601.7	6 904.6	8 386.4
Profit (MWK/acre)	42 971.7	27 937.5	41 953.6

*MWK = Malawian Kwacha

Table 4.2b Maize budget with fertiliser use

Maize Fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	501.8	400.1	500.2
Price (MWK/Kg)	170	150	180
Turnover (MWK/acre)	85 301.9	60 021	90 031.5
Costs (MWK/acre)	18 635.2	18 200.2	22 523.7
Fertiliser (MWK/acre)	7 575.8	8 033	9 722.2
Seed (MWK/acre)	3 740.3	2 670.9	3 678.9
Labour (MWK/acre)	7 319.2	7 496.2	9 122.5
Profit (MWK/acre)	66 666.6	41 820.8	67 507.8

As can be seen from the Tables 4.2a and 4.2b above, the 2016/2017 and 2018/19 seasons saw above average yields for maize, which may be attributable to the favourable climatic conditions for maize production. The International Food Policy Research Institute, who conduct monthly reports on commodity prices in Malawi and other developing countries, observed an increase of 82 MWK/Kg of maize between April 2018 and April 2019, justifying the increase derived from the study data in the table above (IFPRI, 2019).

4.2.2 Groundnuts

Groundnuts are one of the most widely grown crops after maize and tobacco in Malawi. It has been identified as one of the promising crops to replace the crucial yet uncertain tobacco crop (FAPA, 2018). Groundnuts are perhaps the most important legume grown in Malawi by smallholder farmers and their inclusion in this study is significant.

4.2.2.1 Inputs

The input costs of groundnuts include seed, labour and fertiliser (where applicable). Access to inputs is done through the local market or a nearby agrodealer where possible. During some seasons, the FISP subsidy programme provides groundnut farmers with subsidised inputs for their crop – for example, the FISP 2018/19 programme provided subsidised legume seed.

4.2.2.2 Seed

Similar to maize, the data suggests that almost half the seed used in groundnut production is recycled seed. A challenge to the smallholder groundnut producers arises when seed is recycled year on year, which could result in poorer and poorer quality seed. An explanation for the desire to recycle seed comes from a dual seed related constraint to groundnut production.

Firstly, a high seed rate (32-40 kg per acre) would require a relatively significant investment if all were to be purchased seed. Secondly, a low seed multiplication ratio for certified seed producers makes access to improved, certified seed varieties unattainable to smallholder farmers (Nyondo & Nankhuni, 2018). Thus, recycled seed becomes the most common groundnut seed source. Nonetheless, a higher application rate and cost per kg of bought groundnut seed, together with the opportunity cost attached to the recycled seed, leads to a higher input seed cost when compared to maize.

4.2.2.3 Labour

Groundnuts are also more labour intensive than maize, requiring approximately 40 man-days per acre. A large portion in the increased labour requirement is testimony to the harvesting process of groundnuts, which is a more complex and labour-intensive practice. For example, according to ICLARM & GTZ (1991), the harvesting stage of maize requires around 4 man-days of labour per acre whereas the same process for groundnuts is in surplus of 7 man-days per acre.

Since the groundnut budgets are correlated to shelled groundnuts, most of the additional harvesting labour requirement is allocated to extracting the nut from the shell. This is often a slow and tedious process done by hand. The study keeps the rate of hired labour constant across the additional labour requirement and recognises the dominant use of household labour.

4.2.2.4 Fertiliser

Although the application of fertiliser to groundnuts is not hugely common among Malawian smallholders, given its efficient utilization of residual soil fertility, the study still makes provision for its occurrence from a smaller sample size of farmers who used fertiliser on their groundnuts (Chikowo, Snapp & Hoeschle-Zeledon, 2015a). The data suggests a slightly higher application rate of fertiliser per acre of groundnuts resulting in a higher input cost.

4.2.2.5 Output

Although groundnuts are sought after in the international market, Malawi has experienced high levels of aflatoxin contamination in its groundnuts, which has inhibited its export potential. Most of the groundnut marketing is done through informal markets whereby traders and vendors will buy directly from the smallholder farmers at farm gate prices during harvest time (April-June). These traders and vendors then sell the nuts at a price almost double the farm gate price in October to March when peoples' own stocks are depleted (Nyondo & Nankhuni, 2018).

The focus of this thesis lies on the smallholder farmer him/herself, and therefore farm gate prices are the ongoing concern. Across the three study years, the farm gate price of groundnuts has seen a stable increase from MWK350/kg in the 2016/17 season to about MWK400/kg in the 2018/19 season. As for the groundnut yields in southern Malawi, they seemed to be somewhat less volatile than that of maize. However, like maize, groundnut production is still very dependent on the climatic conditions, particularly in Malawi where smallholder farmers are totally reliant on rainfed production.

Table 4.3a Groundnuts budget without fertiliser use

Groundnuts no fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	224.1	200.1	206.6
Price (MWK/Kg)	400	450	450
Turnover (MWK/acre)	89 631.4	90 031.5	92 947.5
Costs (MWK/acre)	16 677	20 436	24 195
Seed (MWK/acre)	7 200	7 800	8 400
Labour (MWK/acre)	9 477	12 636	15 795
Profit (MWK/acre)	72 954.4	69 595.5	68 752.5

Table 4.3b Groundnuts budget with fertiliser use

Groundnuts fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	269.4	240.6	289.4
Price (MWK/Kg)	400	450	450
Turnover (MWK/acre)	107 775.4	108 256.5	13 0217.6
Costs (MWK/acre)	26 917	32 158.7	36 563
Fertiliser (MWK/acre)	10 000	11 402.7	11 968
Seed (MWK/acre)	7 200	7 800	8 400
Labour (MWK/acre)	9 717	12 956	16 195
Profit (MWK/acre)	80 858.4	76 097.8	93 654.6

Looking at Tables 4.3a and 4.3b, one can immediately note that the differences between groundnut with fertiliser and those without – which does not hold as significant a difference in terms of yield. Of course, the production with fertiliser sees a slightly higher yield but as mentioned earlier, groundnuts perform well on residual soil fertility and therefore even without the application of fertiliser have proved to be a rather valuable crop.

4.2.3 Soybeans

Soybeans are well adapted to be produced in all agro-ecological zones in Malawi (Kananji & Monyo, 2013). The produce is widely used to make cooking oil and human foods. Its high protein value has gained in popularity as a cheap alternative to meat - commonly sold as soy 'meat' pieces and earned itself an increasing demand in the manufacturing of animal feeds. Being a legume, soybeans can replenish levels of Nitrogen in the soils, which when used in rotation with maize could reduce the dependency on Nitrogen rich fertilisers, and hence the cost of production of maize. Although the bulk of the soybean production is found in northern Malawi, the crop still forms an integral part of the lives of the southern region farmers.

4.2.3.1 Inputs

The main input costs for soybean production in southern Malawi are seed, labour and fertiliser (where applicable). Again, the FISP subsidy programme can increase focus during some years to provide subsidized soybean inputs such as seed and fertiliser. However, weak extension services and limited access to improved seed varieties and fungicides are identified as key constraints to soybean production in Malawi (Kananji & Monyo, 2013).

4.2.3.2 Seed

The Malawi Government implemented a soybean seed subsidy programme in 2008 to try and promote the production of soybeans as part of an initiative to promote legumes. However, even with the seed subsidy programme, farmers have very limited access to improved soybean seed varieties. Literature reviews such as ACB (2014) indicate that more than 50 percent of the soybean seed used by a smallholder farmer comes from his/her own stocks (recycled seed).

In addition to the opportunity cost attached to recycled soybean seed cost, there are also consequent storage costs as soybean seed can lose condition fast and replanting becomes inevitable (Kananji & Monyo, 2013). To complicate the soybean seed factor, most seed varieties require inoculation with rhizobium, which comes with additional costs. All these costs are built into the seed cost displayed in the budgets.

4.2.3.3 Labour

Like most of the crops grown, the labour requirement for soybeans is made up of land preparation, planting, weeding, fertiliser application (where applicable) and harvesting. Much like that of groundnuts, the harvesting stage is perhaps the most labour-intensive activity. The nature of a soybean pod requires excessive effort to extract the beans, particularly in a country like Malawi where mechanisation is unattainable to the smallholder farmers. Thus, a large portion of the labour requirement is made up of 'thrashing' – a stage of the harvesting period whereby the beans are extracted from the pods. The labour used for this thrashing process is again apportioned according to household (free) labour and hired labour.

4.2.3.4 Fertiliser

Like groundnuts, the use of fertiliser on soybeans amongst the smallholder farmers in Malawi is not a common practise. The nature of a soybean being a legume means it fixes its own nitrogen so fertilisers like urea, which are crucial for maize, are not needed in soybean fields. Soybeans grown in rotation on a field that used NPK fertiliser the previous season do not require additional fertiliser (Chikowo, Snapp & Hoeschle-Zeledon, 2015b).

These factors contribute to the uncommon existence of fertilised soybean crops in the study area and as a result subsidy programmes do not target subsidised fertiliser specific for soybeans. Thus, further solidifying its rare occurrence. To the smallholders who experience poor soil fertility and/or whose budget allows for fertilised soybeans, they tend to apply a median amount of 40kg of fertiliser per acre.

4.2.3.5 Output

Due to the limited varieties currently available to most smallholder farmers and the use of recycled seed, the yields reached by most of the smallholders sits around 60 percent of the potential yield they could reach (Kananji & Monyo, 2013). During the 2016/2017 season, the country experienced its highest national average yield for soybeans in at least eight years. The study data for the southern region supports this occurrence with yields declining on an annual basis since the bumper crop in the 2016/17 season.

Somewhat surprising is the fact that Malawi government has kept the farm gate price for soybean constant across the three study years. However, an analysis of some of the true prices received by the smallholder farmers showed that during the bumper year (2016/17) when there was a large supply of soybeans, some farmers received a mere MWK155 /kg compared to the government imposed farm gate price of MWK280 /kg (MITC, 2020). However, to keep consistency across the study, the farm gate prices were applied to the models.

Table 4.4a Soybean budget without fertiliser use

Soybeans No Fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	356.7	300.1	220.1
Price (MWK/Kg)	280	280	280
Turnover (MWK/acre)	99 868.9	84 029.4	61 621.6
Costs (MWK/acre)	18 377	21 536	24 695
Seed (MWK/acre)	8 900	8 900	8 900
Labour (acre)	9 477	12 636	15 795
Profit (MWK/acre)	81 491.9	62 493.4	36 926.6

Table 4.4b Soybean budget with fertiliser use

Soybeans Fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	359.8	319.5	236.5
Price (MWK/Kg)	280	280	280
Turnover (MWK/acre)	100 746.6	89 473	66 211.8
Costs (MWK/acre)	28 742	33 401.3	37 212.6
Fertiliser (MWK/acre)	10 125	11 545.3	12 117.6
Seed (MWK/acre)	8 900	8 900	8 900
Labour (acre)	97 17	12 956	16 195
Profit (MWK/acre)	72 004.6	56 071.7	28 999.3

The constant soybean farm gate prices seen in Tables 4.4a and 4.4b mean that the profit margins are highly dependent on yields. Like maize and groundnuts, the 2016/17 season saw above average soybean yields - which resulted in sufficient profit margins for soybean farmers. However, for the two subsequent years the soybean yields have declined in the southern region of Malawi for both fertilised and unfertilised soybean production. Thus, suggesting that the yield reductions are climate related. The 2018/19 season saw above-average rainfall in parts of southern Malawi, which may have inhibited the growth of the surface feeder soybean plant.

Additionally, fluctuating soybean yields in Malawi are often pegged to inadequate supplies of improved seed varieties, poor crop husbandry, short-lived seed viability, and processing and utilising technology unfamiliarity (Tinsley, 2009; UNCTAD, 2019). Although Table 4.4b indicates a substantial decline in soybean yields with fertiliser use, the accuracy of this decline may be exploited by the small sample size from which the yields were derived. Again, the median yield figure was used to try keep the value as accurate as possible in the presence of outliers.

4.2.4 Common beans

The common bean (**Phaseolus vulgaris** L) is perhaps the most important crop – alongside maize, for food security in Malawi. Its popularity as a food source and increasingly income generation, is particularly significant to resource poor farmers given its low input cost (Katungi, Magreta, Letaa, Chirwa, Dambuleni & Sospeter, 2017). The nutritional value of the common bean makes it an affordable substitute to more expensive products such as meat. The crop is grown across the whole country, usually intercropped with maize. However, this study makes provision for the crop as a pure standalone crop, to allow for an accurate analysis of its performance in southern Malawi.

4.2.4.1 Inputs

As just mentioned, the common bean gains popularity amongst the resource-poor farmers, due to its relatively low input cost requirements. Access to subsidised inputs through the FISP and extension services were identified as key factors in the decision for smallholder famers in Malawi to grow common beans (Lifeyo, 2017). The FISP subsidy programme further aids resource poor farmers in the production of the nutritiously valuable crop. The input costs accounted for to produce common beans in southern Malawi are seed, labour and fertiliser (where applicable).

4.2.4.2 Seed

Whilst adoption of improved seed varieties is relatively high, limited access to modern bean varieties due to a low interest among private seed multiplication companies, has plagued this segment of the value chain (Lifeyo, 2017). These private seed companies recognise that the smallholder farmers' ability to easily save seed from self-pollinating bean plants limits their profit potentials (Magreta & Jonathan, 2012). Literature reviews such as ACB (2014) suggest more than 60 percent of the bean seed is recycled. The high proportion of recycled seed is matched with a high opportunity cost because of the good prices achieved for beans on the market. The recycled and bought seed needs to be sufficient to satisfy a seeding rate of around 32kg of seed per acre.

4.2.4.3 Labour

The labour requirements to produce common beans are standard. Beginning with land preparation and planting, followed by weeding and fertilizing (where applicable), and finishing with the harvesting process. The common bean is defined as a pulse, and according to ICLARM & GTZ (1991), pulses require similar labour requirements to that of soybeans. This study utilises a labour requirement of about 44 man-days to produce an acre of common beans. With little mechanisation, all of the work is done using what is commonly known as a ‘kasu’ or hoe to work in the fields. The harvesting and processing of the bean is done mainly by hand once the beans have matured.

4.2.4.4 Fertiliser

Common beans are legumes and nitrogen fixators. Therefore, much like soybeans, their need for fertiliser is not as vital as that for maize. From the study sample, very few farmers reported using fertiliser on their bean fields. The small sample size of just 10 farmers who did fertilise, provide a yield analysis which is susceptible to high levels of standard deviation and increases the chances of a type ii error. Therefore, the findings based off this sample may not be conclusive. Nonetheless, data limitations forced the study to utilise the small sample size, which indicated around 40kg of legume suitable fertiliser per acre.

4.2.4.5 Output

In 2013, the projections for the production of beans in Malawi for the next few years indicated a continued growth in both demand and production of the legume (Kananji & Monyo, 2013). However, high fluctuations in the production of beans are associated with high variability in rainfall conditions. National data released by the government of Malawi, indicated a slight increase in the national yield of beans across the past five years. Although the 2018/19 season saw above average rainfall which negatively impacted the yield of beans in the southern region of Malawi. The yields used in the budgets for beans were derived from the median value of the yields of the respective study groups split according to their fertiliser use or lack thereof. In terms of the bean prices, the farm gate prices set by the government exhibited a growing trend over the three study years. From a minimum bean price of MWK300 per kg in the 2016/17 season to MWK420/kg in the 2018/19 season.

Table 4.5a Bean budget without fertiliser

Common Beans No fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	157.6	150.1	110
Price (MWK/Kg)	300	400	420
Turnover (MWK/acre)	47 266.5	60 021	46 216.2
Costs (MWK/acre)	18 176.4	21 513.6	25 524.7
Seed (MWK/acre)	10 886.4	11 793.6	13 374.7
Labour (MWK/acre)	7 290	9 720	12 150
Profit (MWK/acre)	29 090.1	38 507.4	20 691.5

Table 4.5b Bean budget with fertiliser use

Common Beans Fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	160.1	150.1	120.5
Price (MWK/Kg)	300	400	420
Turnover (MWK/acre)	48 015	60 021	50 589
Costs (MWK/acre)	28 541.4	33 378.9	38 042.3
Fertiliser (MWK/acre)	10 125	11 545.3	12 117.6
Seed (MWK/acre)	10 886.4	11 793.6	13 374.7
Labour (MWK/acre)	7 530	10 040	12 550
Profit (MWK/acre)	19 473.6	26 642.1	12 546.7

Evident from Tables 4.5a and 4.5b above is the possible inaccuracy of the fertilised yields. The data from the small sample size of bean farmers using fertiliser suggests that their yields are not as substantial as those that produce beans without fertiliser. The result of this is uncharacteristically low profit margins for farmers using fertiliser on beans. Although perhaps not on the scale suggested in Table 4.5a, beans do perform well on residual fertility and therefore all things considered, may be a better option for a farmer who is unable to supply fertiliser to his/her crop.

4.2.5 Sweet potatoes

In Malawi, and the rest of sub-Saharan Africa, diet deficiencies are a common occurrence. Vitamin A in particular, is deemed deficient in 60 percent of children under five and 57 percent of non-pregnant women in Malawi (Sindi, Kiria, Low, Sopo & Abidin 2013). Not only are sweet potatoes regarded as a crucial source to combat such deficiencies, but the tuber is also perhaps the most yield-stable crop grown in Malawi. Most varieties grown in Malawi can tolerate drought a lot better than many of the other crops grown in the country; making it the chosen crop when other crops fail (Sindi *et al.,* 2013).

4.2.5.1 Inputs

The standardised make up for inputs in this study sticks for that of sweet potato. Namely, seed, labour and fertiliser (where applicable). In addition to the nationwide subsidy programmes, some farmers belong to the farmer groups or organisations such as NASFAM (National Smallholder Farmers' Association of Malawi). Group members are granted access to new and improved sweet potato varieties, financial assistance as well as agronomic training to better their crop practices (Sindi *et al*., 2013). Through these groups, farmers can share costs among all the group members and therefore reduce individual input costs. However, according to the study by Sindi *et al.* (2013), only an average of about 40 percent of their interviewed farmers belonged to a farmers' group.

4.2.5.2 Seed

The seed input for sweet potato is rather complex. Planted sweet potato can either be done by planting a sweet potato itself or, and probably the more common method, is done by planting vines from a sweet potato plant. The latter method requires access to vines at the time of planting (usually with the onset of the rains). However, a major challenge to the vine materials is that the farmers tend to only gain access to and/or receive the vines two or three weeks into the rainy season. As a result, farmers may not realise the maximum yield potential of their crop (Sindi *et al.*, 2013).

Most farmers sourced their vines either from their own sweet potato plants (owing to the late planting times) or from other neighbouring farmers. Those who sought new and improved varieties would have to buy the vines from nearby farmers who had improved varieties. During the dry season, farmers were forced to keep vines alive so that they were available come planting time. To do so, most farmers conserved vines by planting them in low-lying areas and caring for them (Sindi *et al.*, 2013). This requires a small 'maintenance' cost which was accounted for in the seed input cost.

4.2.5.3 Labour

The resilient nature of sweet potatoes meant that once the vines/seed were planted, they were left to grow with little attention needed besides a weeding practise when required. Of course, those who chose to fertilise would require an extra labour input when necessary. Overall, the labour requirement for sweet potatoes is rather low. The land preparation requires the biggest chunk of the labour input (63 percent) because the sweet potatoes require much bigger ridges than other crops (ICLARM & GTZ, 1991). The study recognises a requirement of around 40 man-days per acre for sweet potato production in southern Malawi.

4.2.5.4 Fertiliser

Very few farmers fertilised their sweet potato crops. In the 2017/18 season, from a sample size of 162 smallholder farmers growing sweet potatoes in southern Malawi, only 8 farmers applied fertiliser to the crop. Farmers tend to prioritize their fertiliser for maize and when grown in rotation, expect the sweet potato to utilise residual soil fertility from the maize season. Sweet potatoes' ability to constantly produce sufficient yields to meet the requirements of a Malawian household without fertiliser, means farmers tend to exclude the extra input cost. Although, the yield results of farmers who did apply fertiliser to their sweet potato are significantly higher but these results may be inaccurate due to the small sample size.

4.2.5.5 Output

On paper (and in the crop budget), the high yields of a fertilised sweet potato crop are met with attractive profit margins. Fertilised yields are constantly above 1,5 tonnes per acre for the three study years, which equates to substantial profits when merged with the three input costs (labour, seed and fertiliser). Assuming these results area accurate, these profit margins would hold in the perfect world if the smallholder were fortunate enough to sell all his crop at once to a processor or cooperative, such as Universal Industries for example.

However, these lucrative markets are only available to a select few who are lucky enough to have contracts or connections with these processors. To the average sweet potato farmer, they rely on selling their crop bit by bit in the informal markets. As a result, they will not be able to sell all their crop at once and are therefore left with a predicament to try store the crop. Malawian smallholders lack the physical capacity to store large volumes of sweet potato and are forced to sell what they have as soon as possible.

Inevitably, the market becomes flooded during harvest time with very few opportunities for processing and storage, which means tonnes of sweet potato goes to waste each year (AgriLinks, 2018). The study makes provision for such a scenario and its specifications will follow shortly. As for the prices of sweet potato, the minimum farm gate price specified by the government remained stable across the three study years, varying by only MWK5/kg. This meant most variations in the profit margins of sweet potato were attributable to production circumstances.

Table 4.6a Sweet potato budget without fertiliser use

Sweet potato No fertiliser			
Season	2016/17	2017/18	2018/19
Yield (Kg/acre)	702.5	700.2	640.2
Price (MWK/Kg)	160	165	165
Turnover (MWK/acre)	112 406.7	115 540.4	105 636.9
Costs (MWK/acre)	68 445	71 280	74 115
Seed (MWK/acre)	59 940	59 940	59 940
Labour (MWK/acre)	8 505	11 340	14 175
Profit (MWK/acre)	43 961.7	44 260.4	31 521.9

Table 4.6b Sweet potato budget with fertiliser use

Sweet potato Fertiliser			
Season	2016/2017	2017/2018	2018/2019
Yield (Kg/acre)	1 708	1 702.4	1 690.6
Price (MWK/Kg)	160	165	165
Turnover (MWK/acre)	273 286.9	280 905.8	278 947.6
Costs (MWK/acre)	98 685	105 808.2	109 515
Fertiliser (MWK/acre)	30 000	34 208.2	35 000
Seed (MWK/acre)	59 940	59 940	59 940
Labour (MWK/acre)	8 745	11 660	14 575
Profit (MWK/acre)	174 601.9	175 097.6	169 432.6

Evident from Tables 4.6a and 4.6b is the constant farm gate prices for sweet potato and the stable yields for fertilised sweet potato. As can be seen in Table 4.6b, the budget makes for attractive reading on paper. However, the Malawian smallholder farmers and their experience, know the struggles and limitations associated with large volumes of sweet potato. These limitations are not captured in the financial budget of the crop and are therefore explained in more detail later in the constraints section.

4.3 Intercropped crops

Across the whole country, where subsistence farming is the way of life, intercropping secondary crops amongst the main crops is a popular practice that has been around for decades. Although intercropping does contribute to the level of diversification held by the farmer, the intercropped crop merely 'piggy backs' off the main crop and is financially insignificant when compared to the main crop. These secondary crops were excluded from the model because it is challenging to allocate input costs to the intercropped crops as they are not grown as pure stand crops and rather feed off the main crop.

Nonetheless, the influence of a few of these intercropped crops on food security and income generation may be small in most cases but cannot be ignored. There are numerous crops in Malawi which are intercropped depending on the farmers preferences. This study makes a note of a few of the main ones in its opinion.

4.3.1 Pigeon peas

Pigeon peas, *nandolo* in the local Chichewa language, is a drought-resistant legume with a high protein content. Its occurrence in Malawi is particularly common in the southern region, owing to the semi-arid conditions. To the local population in southern Malawi, pigeon peas are often the legume of choice in their diets as a replacement to the more expensive protein alternatives such as meat and dairy (Jones, Freeman & Monaco, 2002). In addition to its dietary demand, pigeon peas provide relatively attractive returns, especially when one considers the low input requirements of the legume.

High and stable farm gate prices around 320MWK/kg and drought-resistant yields have the potential to provide smallholder farmers with much needed cashflow. Normally, pigeon peas mature much later than the primary crop. This is a valuable benefit as it provides a source of cashflow or food when other stocks may be depleting (Jones *et al.,* 2002).

4.3.2 Cassava

Cassava is an important food crop in Malawi, so much so that in the lakeshore regions around Lake Malawi, it is considered – alongside maize, to be the staple food crop (Chipeta & Bokosi, 2013). In the lakeshore areas of Malawi (outside the study area), there are records of pure stand cassava crops, especially in marginal soils where other crops will fail. In the southern region of the country, cassava is commonly grown on the boundaries of a smallholders' field where it feeds off residual fertility from the primary crops. The cassava root is usually sold within the villages or confined to nearby towns where it is sold in the local market (Chipeta & Bokosi, 2013). Production of cassava in Malawi is growing, owing to an increased area allocated to the root crop, as farmers see the potential in cassava as a cash crop as well as a staple food crop.

4.3.3 Pumpkin

Pumpkins are intercropped with a lot of the primary crops listed in this study. The creeper-like growth of a pumpkin plant along the floor ensures it does not compete with the primary crop. Both the leaves and squash are used to diversify the household diets and add provision towards food security. Pumpkin seeds are usually recycled or sourced cheaply from neighbours or in the local market. Once planted, the pumpkins are left to grow without requiring much attention and tend to mature at similar timings to the primary crops.

These are among a few of the several crops chosen by smallholder farmers to intercrop within their fields. Although they are not included in the model of this study, their importance to food security and in some cases contribution to cash flow, is valuable and their coexistence with the results of this study should be promoted.

4.4 Constraints

To prevent the model from producing infeasible recommendations and to ensure the results are applicable to the study nature, certain constraints both minimum and maximum need to be implemented. The Cambridge dictionary defines a constraint as “something that controls what you do by keeping you within particular limits” (CambridgeDictionary, 2020). The smallholder farmers are constrained by several factors which limit their capacity to expand exponentially.

Jew, Whitfield, Dougill, Mkwambisi and Steward (2020) performed focus group interviews with smallholder farmers in Southern Malawi, they found availability of money (capital) and availability of labour to be among the top production constraints faced by the farmers. Following this and in-line with the study objectives, the maximum constraints implemented for smallholder farmers in Southern Malawi in this study are land, capital, labour and sweet potato acreage. The minimum constraint implemented in this study to promote food security is a minimum maize acreage constraint.

4.4.1 Land

According to Asfaw & Maggio (2018), more than 70 percent of the smallholder farmers in Malawi have less than one hectare on which to farm. This equates to just under two and a half acres per household. Therefore, the quadratic model must recognise a limit on the amount of land that can be allocated to each crop. This farm size limit is used as the defining specification for the three models used in this study (which are further branched according to fertiliser use or lack thereof).

The first model is for small farms which are limited by a land constraint of two acres. Given the average farm size in Malawi is not more than 2.5 acres, this model is the most applicable to the study area. The second model is for medium farms which are limited by a land constraint of four acres. Finally, the least populated model, for large farms which are limited by a land constraint of six acres. The terms small, medium and large are all relative to this study in the context of small-scale farmers.

4.4.2 Capital

The term capital is no foreign word among economists, it refers to wealth in the form of money or assets that are used to perform economically useful work. There are several types of capital with the two most common being financial capital – referring to cash and cash equivalents for example, and human capital – such as labour health and training. This study recognizes labour (human capital) as its own constraint.

The assets included in this study under capital generally refer to the availability of financial wealth with which a farmer can invest in his smallholder farm. Their available capital affects their ability to purchase inputs such as seed, labour and fertiliser as well as other production assets such as equipment like hoes. Given the extremely poor nature of Malawian smallholder farmers, the capital limitations most certainly act as a binding constraint on their production capacities.

Following their reliance on agriculture as a source of livelihood, most smallholder farmers rely on income from the previous harvest to fund their next season. Some smallholders venture to off-farm activities as a source of income but must forfeit their own labour time that could have been spent on their crop to do so. Access to credit is a challenge to all smallholder farmers in Malawi. In interviews conducted with 59 households in Malawi by Lindsjö, Mulwafu, Andersson Djurfeldt and Joshua (2020), only 14 reported having received credit or borrowed money in the last five years.

Following the challenges faced by farmers to obtain sufficient capital to invest in inputs for their crops, a maximum capital constraint must be implemented into the models. The financial amount a farmer can invest in his crop will vary between each farmer. Thus, this study follows the findings by FAO (n.d.) who suggest on small farms, farmers spend 45 percent of the crop value on inputs and 39 percent of the crop value on inputs on the bigger farms consisting of more than 2 acres of arable land.

After extracting the labour input element, given it has its own constraint and following the FAO guidelines, the capital constraint for small smallholder farmers who do not use fertiliser on their crops is around MWK46 500. To those who can apply fertiliser to their crop, their capital constraint for a small farm is MWK95000. For medium farms without fertiliser use, the capital constraint lies at MWK80 000 and for fertilised farms at MWK150 000. For large farms (constrained by 6 acres of land) the capital constraint of unfertilised farms is MWK120 000 and fertilised farms is MWK219 000.

4.4.3 Labour

As already mentioned, the labour input component of a farming activity is comprised of free household labour and salaried or hired labour. According to the data analysed for this study, household labour accounts for as much as 80 percent of the labour requirement on a 2-acre plot. The study makes an assumption based on interviews with local farmers that on average, the portion of hired labour increases by 10 percent as we move from small to medium to large farms. Jew *et al*. (2020) identified that in Southern Malawi, the average family labour available was 4.4 people. Following this, the study uses recommendations by Leach (1995)[cited by (Kamanga, Kanyama-Phiri & Minae, 1998)] that labourers work 20 days in a month for the four main cropping months (November to March) on a 2-acre plot. This equates to a total of 385 man-days.

However, this represents the 'perfect world' scenario, whereas in the real-world certain obstacles prevent farmers from spending so much time in their lands. From their surveys on Southern Malawi farmers, Jew *et al.* (2020) highlighted household health to be the top ranked constraint on agricultural productivity and other factors such as climatic conditions which also contributed to a loss in labour days. From a household survey of 201 farming families, an average of 70 man-days were lost due to household health issues and other restrictive factors (Jew *et al.,* 2020).

Therefore, a more realistic estimate of household labour used during the cropping season is about 314 man-days. These man-days represent the free household labour so with the additional hired labour, the total available man-days for a small (two acre) plot are equal to 393 man-days. For a medium and large plot, the household labour man-days remain constant, but the hired labour contribution increases with respect to the increase in acreage. A medium farm in constrained by 448 man-days of labour. Lastly, a large farm has 523 man-days available. To successfully integrate this constraint through a quadratic model, a financial value which compliments the crop-specific budgets need to be assigned. To do so, a daily wage of MWK800 (median value used in the study) for hired labour is used to attach a financial value to the respective labour constraints.

4.4.4 Maximum sweet potato acreage

Although the figures make sweet potato seem rather attractive, when grown without the required machinery, storage, processing and marketing facilities it can prove to be in vain. The potential large volumes of sweet potatoes combined with a limited storage capacity and restricted marketing platform means that the potential for sweet potato losses is a significant reality.

Since the losses are related to an excess supply of sweet potato – a prominent feature when the crop is fertilised, a limitation to the number of sweet potatoes is introduced to minimise the amount of produce that goes to waste. The yields attained from unfertilised sweet potato crops allow for the study to limit the acreage for sweet potatoes to one acre. Whereas the higher yielding fertilised sweet potato crop is confined to half an acre. These constraints were derived by analysing the current acreage trends of sweet potato growers in Southern Malawi. These farmers have grown the crop every year and know their capabilities when it comes to storing and selling the produce.

Although the limitations introduced are not the absolute maximum acreages noted in the study, they are among the upper acreage limits grown among either fertilised or unfertilised fields, respectively. The handful of farmers who grew acreages above the specified limit were assumed to have some sort of a contract agreement with a processor or are irregularities. Whether the farmer is classified as a small, medium, or large farmer does not mean they are exempt from the storage and marketing challenges faced by sweet potato growing. Therefore, the same acreage limitations apply across the three farm size categories.

This study recognises that there are smallholder farmers who have a market be it through a contract or other agreement, with processing companies such as Universal Ltd who facilitate for larger volumes of sweet potatoes to be produced by the smallholder farmer. However, these fortunate farmers are currently in the minority. Thus, this study exempts such a scenario from the study and so the described limitation holds.

4.4.5 Minimum maize acreage

As mentioned earlier in this chapter, maize is the staple food crop across most of Africa, and Malawi is by no means an exception from this. The study's reference to minimising risk entails a factor of food security. One of the results of falling victim to the potential risk faced by these Malawian smallholders is hunger. Thus, to minimise risk and ensure food security, this study ensures enough land is allocated to the staple food crop in the respective models.

As introduced earlier, the minimum maize requirement to be produced from a smallholder field to supply the household regardless of the farm size is 387 kilograms. The land requirement to achieve this quantity is dependent on whether the crop is fertilised or not. The non-fertilised maize crop is constrained by a minimum maize acreage of 1,3 acres. For the fertilised maize crop, a minimum land allocation of 0,75 acres is introduced into the model.

4.5 Assumptions

Perhaps life in the perfect world would exempt the need to make assumptions, but in the real world specifically looking at data demanding studies, their existence is necessary to fill unattainable gaps. Their existence is made under supportive theories and is implemented in such a way to minimise the jeopardy that it may cause on the accuracy of the study. Agricultural research in Malawi is plagued by the undeveloped nature of the country, combined with the lack of financial/economic 'bookkeeping' records on the smallholder farm level. This makes the challenge of sourcing the required data to perform a study that much more compelling. Following this, the study implements the subsequent assumptions in an attempt to fulfil the required data 'gaps' in the most accurate way possible.

The study assumes that all the crops are valued in accordance with the government established farm gate prices. In some cases, farmers may sell some of their produce to a local vendor at a price less than the farm gate price in one village, whereas a different village receives premium prices. Therefore, to ensure consistency, the farm gate price was used across all crops. This means that the primary risk element derived in this study is that of production risk, the market risk is dependent on the government's farmgate prices and their ability to ensure that these prices are adhered to by local vendors.

Even in the cases where farmers may not have sold all their crop, the retained produce is still valued at the farm gate price for each crop to allow for comparisons between the crops to be drawn on the farm level. In line with the farm gate prices, the study also assumes the farmers are not attached to any form of contract and are rather operating under their own decisions.

Labour has always been a contentious issue in Malawi given the primary use of household labour of which child labour forms a part. This study's literature reviews, and primary data sources indicate that an average of 80 percent of the labour requirement is fulfilled by household labour on a two-acre plot. The study then assumes that the portion of hired labour increases by 10 percent as one moves from small to medium to large farms. This assumption is based on the notion that bigger farms do not necessarily imply bigger households, which means the demand for hired labour to complete the extra labour requirements increases. Household labour has no opportunity cost because agriculture is the pivotal facet of most household lifestyles.

The study assumes that all the crop budgets derived on a per acre basis are constant across the three farm size categories except for labour, which is adjusted as per above. The quantity of farmers operating in the medium and large farm categories are insufficient and lack the complexity to derive accurate budgets from. Therefore, the per acre budgets derived from the small farms were elaborated across the other farm categories. However, the constraints were adjusted accordingly.

Given the lack of infrastructure and financial capacities to irrigate, the study assumes that all crops in this study are purely rain-fed. This is not a presumptuous assumption as barely two percent of Malawi's arable land is irrigated (Chafuwa, 2017). Inline with this assumption follows another which assumes that the farmers have a single cropping season in a year. There are a few areas where water is abundant such as the Shire River and Lake Chilwa floodplains which allow for conventional irrigation and winter cropping, but these cases fill an insignificant part of the smallholder populations and are therefore not included in this study.

The last assumption pays reference to the farms that fertilise and those that do not. When the study segregates a farm that fertilises with one that does not, it is assuming that either all crops grown on the farm are either fertilised or none. The study does not account for farms that may only choose to fertilise one crop in their portfolio. Comparing a fertilised crop with an unfertilised crop is like comparing apples and oranges. Therefore, for a standardised comparison, this assumption holds.

4.6 Limitations

Besides the study area and target population, this study is bound by a few other limitations. The focus of the study to minimise risk using crop diversification is limited to pure stand crops. From these pure stand crops, the study limits its focus on five crops based on their importance and data availability. Although tobacco is perhaps the most important pure stand crop grown in Malawi, it serves as a beacon as to why farmers need to diversify following the low and volatile returns from tobacco crops in recent years.

For this reason, the study excluded its existence in the model. The pure stand crop limitation excludes the effect of intercropping from the model run in this study due to the inability to allocate input costs under the existence of intercropping. However, although the model may exclude the secondary crops that piggyback off the main stand crops, the study still makes provision outside of the model for and promotes their presence.

The study also limits the financial performance of each crop to the farm level. This means that the influence of certain costs beyond the farm level production, such as transport costs or marketing costs, are excluded from the crop budgets. A large portion of the crops produced by farmers in this study are consumed in the household or in the village/market close by. Together with the deemed triviality of the resultant transport and marketing costs, a variation in distances, methods and volumes of produce transported makes the availability of such costs ambiguous. Therefore, to avoid standardising costs unnecessarily, these factors were excluded. Their relevance to answer the study objective is also negligible and thus their exclusion does not jeopardise the accuracy of answering the objective in a prominent manner.

One will also notice the limitation of this study to only include crop portfolios. Although livestock forms an integral part of the agricultural world and even so in Malawi, the subsistent nature of the smallholder farmer tends to see them prioritise their capital on crops. This by no means excludes the existence of livestock among smallholder farmers, in fact almost every household owns free roaming village chickens (DAHLD, 2004). These chickens, and often the same for other livestock, are left during the day to roam freely throughout the village and surroundings and therefore are often not fed supplementary feeds and in some cases require little to no labour. Therefore, to identify the running costs of this livestock would prove to be a mammoth task and thus this study limits its diversification strategy to the more popular and prioritized crop portfolios.

The last limitation to recognise in this study is that of sample size. Although the target population was large and there were sufficient growers of each crop in the study area, when it came to further sub-dividing the sample population according to their use of fertiliser or not, some crops were left with an extremely small sample size. The study tried to extrapolate the required figures as accurately as possible, but such a limitation is recognised, and its effects noted where applicable.

4.7 Conclusion

The potentially boundless nature of this study required an explanation and consequent motivation for the elements, which formed the pillars and guided this study to achieve its desired goals. Following an analysis of the intensive data sheets and supportive literature reviews, this chapter identified the key crops grown in the study area - which form an integral part of a Malawian smallholder farmer and his/her household. These crops were deciphered individually into gross profit margins which, complemented with the appropriate constraints, were inputted into the quadratic risk programming model.

In an attempt to accurately extend the study, aim and its intended benefits across as large a target group as possible, the quadratic risk programming model was configured to capture three different farm size groups – further decoded according to fertiliser use, thus, resulting in a total of six model scenarios. Although these scenarios could be further extrapolated again and again, the study introduced limitations to ensure the feasibility of the research and its objectives. The intensity of the challenges faced in this study increased when controversial elements such as family labour were introduced. It therefore became necessary to introduce certain assumptions as accurately as possible to ensure no gaps or elements were ignored.

Chapter 5: Results and Discussion

5.1 Introduction

The importance of diversification and its specific relevance to agriculture is met with the predicament to identify specific portfolios, which optimise the results from such a diversification strategy. The motivation to find such a portfolio, and the methodology and empirical implication of the tool thereof were discussed in chapters 2, 3 and 4, respectively. The products of this in-depth process provide supportive and extended contributions to the literature and research already conducted in Malawi. The primary contributions of this thesis optimise the use of diversification to provide risk-minimising strategies for smallholder farmers in southern Malawi. Arising from this primary contribution are specific crops whose returns, when combined with other crops in the study, provide maximum levels of return in the presence of minimising the level of variance (risk) to do so.

Section 5.2 provides a presentation and concurrent analysis of the results specific to each of the six scenarios identified in this study. This is followed by section 5.3, which sees a general discussion about the findings and proposes possible ways to promote the findings and realise the most potential from the results. Section 5.4 concludes the chapter.

5.2 Efficient risk-return trade-off

As mentioned earlier, the aim of this study was to determine how smallholder farmers in southern Malawi can use diversification to minimise risk, whilst still achieving optimal levels of return. The subsequent segments of this chapter provide a detailed description of the cropping portfolio suggested by the QRP model based on the historical data, which corresponds to the respective farmer scenario. The analysis also provides a sensitivity style analysis of how the levels of risk are influenced by a change in levels of return.

All the trade-offs discussed occur along the efficient risk-return frontier and thus, whichever level of risk is desired is matched with an optimum return figure and consequent diversification portfolio. The aim of the QRP model is not to maximise income, but rather to minimise risk (Kobzar *et al.*, 2002). Therefore, income is treated like a constant parameter in the model and then the cropping pattern to achieve that income level at a minimum level of risk, is generated.

This study uses a Linear Programming model to determine the maximum income level for each farm scenario relevant to the respective constraints. This figure forms the maximum income level without considering any risk-avoiding instruments. From this 'upper bound', the income level is shifted parametrically downwards to obtain basic solutions - which are used to plot the efficient E, V frontier (expected income vs variance). The income term used in this model refers to expected net profit. The model also uses standard deviation instead of variance for easier interpretations.

The E, V frontier indicates the efficient trade-off between risk and return. Any point lying above the frontier is infeasible and unattainable. Points lying below the curve are inefficient and not optimal - for example more return can be achieved with a different portfolio combination at the same level of risk. Any combination along the curve offers efficient combinations with respect to risk and return. In economics, the use of a marginal analysis is useful to pin-point trade-offs involving marginal gains and marginal costs.

However, in this case, the subjective nature of risk means such a result may not be applicable to every farmer as they have different perceptions of risk. To find the exact optimal portfolio on the curve requires each farmer's individual risk preferences to construct a utility function. As this study is not targeted at a single farmer, such a task deviates from the study's aim. Instead, the study analyses the frontier to provide recommendations to a varied level of risk takers who can understand which crops portfolios will result in a higher return or lower risk.

The slope of the E, V frontier indicates how much return is gained/forfeited from an increase/decrease in the amount of risk exposure. Areas on the frontier with a steep slope indicate that a proportionately larger amount of return can be achieved by only taking on a small additional amount of risk. Where the curve starts to flatten out signals that to gain more reward, an increasingly larger amount of additional risk is needed.

5.2.1 Small farms with no fertiliser application

Pressure on land in Malawi is growing in line with the population growth. As a result, the small farms are the most popular size category in this study. A reminder that this study categorises a small farm as less than or equal to two acres of arable land. There is a fair portion of these small farm farmers who lack the financial ability to fertilise their crops. The risk of crop failures is at its highest amongst these farmers and thus it is important to provide a diversification strategy which minimises their exposure to such a risk.

Using mathematical programming, the maximum level of expected profit attainable by small farm farmers, who do not use fertiliser, is MWK98 211. This figure is reached when no risk-aversion strategy is implemented and therefore the level of variance (risk) is extremely high. After parametrically reducing the level of return through the model, the efficient E, V frontier is generated.

Table 5.1 Portfolio results for a small farm with no fertiliser

Run	1	2	3	4	5	6	
Expected profit (MWK)	70 000	75 000	80 000	85 000	90 000	98 211	100 000
Standard deviation (MWK)	10 470	10 500	10 540	10 610	10 790	11 230	11 230
	Land allocation (Acres)						
Maize	1,3	1,3	1,3	1,3	1,3	1,3	Infeasible solution
Groundnuts	0,07	0,14	0,22	0,36	0,5	0,7	
Beans	0,33	0,33	0,33	0,26	0,2	-	
Sweet Potatoes	0,16	0,16	0,15	0,08	-	-	
Total usage	1,86	1,93	2	2	2	2	

The results reflect the old-age phrase of 'high risk high reward'. The highest feasibly attainable return calculated with linear programming is MWK98 211. This value makes full use of the capacities of the farm subject to the respective binding constraints – in this case land and maize minimum.

The profit maximising portfolio includes no risk-avoiding instrument. The variance (risk) of this portfolio - which corresponds to the high return, is unsurprisingly large at 126 053 600. The variance figure is a measure of the risk associated with the portfolio. A better look at the relationship between risk and return will be shown on the E, V frontier shortly. Table 5.1 provides a visible breakdown of the compilations of the diversified portfolios which minimise the level of risk to achieve the prespecified profits.

Clearly evident from Table 5.1, is that the lowest risk levels are met with the greatest number of crops in the portfolio. The most rewarding, yet most risky portfolio is only made up of two crops, namely maize and groundnuts. As additional crops are presented into the portfolio, the level of risk decreases matched with a logarithmic decrease in return. This notion introduces the trade-off between risk and return, which is portrayed graphically below.

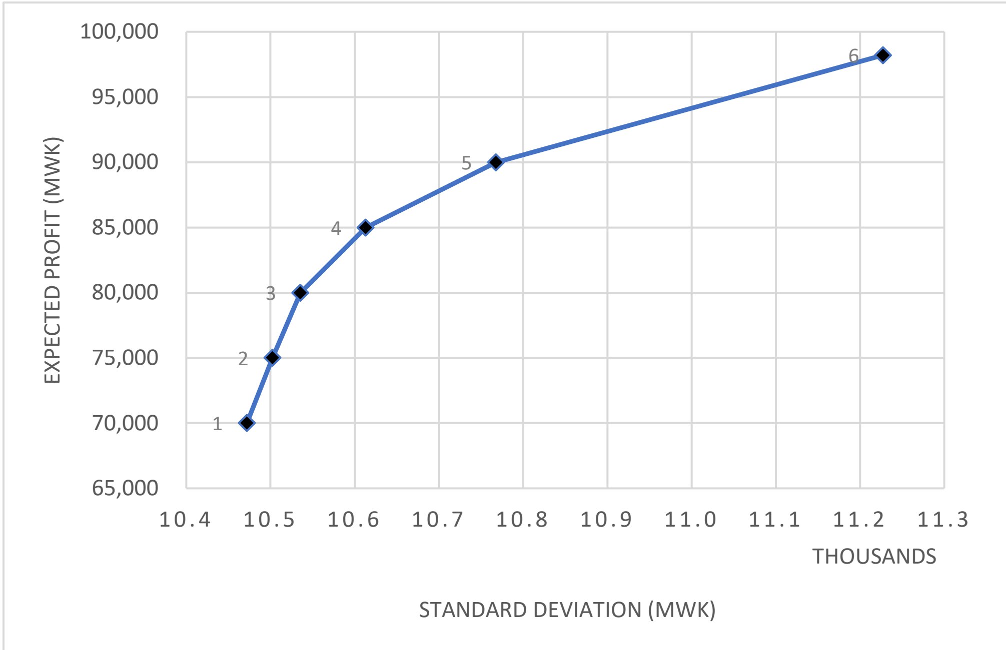

Figure 5.1 E,V frontier for small farms with no fertiliser

Moving from left to right on Figure 5.1, we see that more risk equates to more reward. However, a look at the concave nature of the frontier and the slopes of the curve, one will note that there is the opportunity to significantly increase reward at the cost of slight increase in additional risk. Where the slope of the frontier is steep, i.e. between run 1 and 4 on the graph, such is the case.

Moving across to points 5 and 6 requires a substantially higher amount of additional risk for the benefit of not as much additional reward. The gradient from run 1 to 2 is 0,01 which means an increase in standard deviation by one unit increases reward by 0,01 units. Moving from run 4 to 5, the slope is much lower at 0,002 - which indicates an increase in variance by the same amount as from run 1 to 2. Thus, resulting in a much lower increase in reward.

Therefore, the biggest noticeable increase in reward in response to a unit increase in standard deviation, comes from run 1 to 2, followed by a diminishing rate as one moves from left to right on the frontier. The runs indicated in Figure 5.1, correspond to the portfolio compilations portrayed in Table 5.1. The notable jump in reward from run 1 to run 2 is primarily due to an increased allocation of land to groundnuts. From run 2 to 3, more groundnuts are allocated to the portfolio with fewer sweet potatoes being grown.

As depicted in Table 5.1, the least standard deviation (risk) is found in the runs which combine the most different crops; this pays testament to the effect of covariances and diversification. To the farmers looking to take on more risk, the model suggests moving away from the likes of beans and sweet potatoes and focusing on groundnut and maize production (a reminder of the maize minimum constraint to promote food security). The model completely excludes the allocation of land to unfertilised soybeans. Based on the historical performance of unfertilised soybeans, the model identified alternatives which outperform soybeans with respect to its risk-return nature in a portfolio context.

Overall, as indicated in Table 5.1 for smallholder farmers who occupy a small farm and lack the ability to fertilise, they are bound by the minimum maize constraint to promote food security, which occupies the majority of their land. The QRP model indicates a high marginal value attached to the maize minimum constraint, this means that when compared with the other crops in the model, an increase in the maize minimum would increase the level of risk by the large marginal value. Without the maize minimum constraint in place, the model would not indicate to grow the noted level of maize.

However, as the staple food for most Malawians, it is crucial to promote the need for food security. The remaining land is divided among groundnuts, common beans and sweet potatoes with groundnuts gaining proportion for a farmer willing to take on a bit more risk for more reward. To the less-risk-seeking farmers, a small portion of land to groundnuts, slightly bigger piece to sweet potatoes and still bigger allocation to common beans will suffice.

5.2.2 Small farms with fertiliser application

Following the implementation of various subsidy programmes such as the FISP (Farmer Input Subsidy Program) mentioned in this study, there is a significant amount of smallholder farmers who fall into the small farm size category (less than 2 acres) who are able to fertilise their crops. According to the Food and Agriculture Organisation, more than 75% of smallholder farmers have access to fertiliser (FAO, 2018).

The linear programming model created for this scenario generates a maximum attainable profit of MWK193 173 across their 2 acres. Again, this is the return which holds with no risk aversion strategy and is therefore the riskiest portfolio. The study parametrically reduces this expected profit figure in MWK10 000 increments to create the efficient E, V frontier. The results from the QRP model for a small farm which uses fertiliser, are displayed below.

Table 5.2 Portfolio results for a small farm with fertiliser

Run	1	2	3	4	5	6	
Expected profit (MWK)	145 000	155 000	165 000	175 000	185 000	193 173	195 000
Standard Deviation (MWK)	10 480	10 670	11 020	11 700	12 590	13 830	13 830
	Land allocation (Acres)						
Maize	0,75	0,75	0,75	0,75	0,75	0,75	Infeasible solution
Groundnuts	0,06	0,16	0,29	0,43	0,57	0,75	
Beans	0,48	0,54	0,42	0,25	0,08	-	
Sweet Potatoes	0,5	0,5	0,5	0,5	0,5	0,5	
Soybeans	0,002	0,02	0,04	0,07	0,1	-	
Total usage	1,792	1,97	2	2	2	2	

Evident from Table 5.2, is that across all portfolios, the model is constrained by the maize minimum and sweet potato maximum limitations. The higher expected profit portfolios are further constrained by land. Visible from Table 5.2 is the use of groundnuts on the diversification strategy. As more expected profit is desired, more land is allocated to groudnut production. Groundnuts are second to sweet potatoes in terms of their expected profits and matched with the third-highest standard deviation – owing to its nature in the risk-retrun portfolio.

The inverse scenario is found for beans as its historical results indicate standard deviations, making it a more stable yet conservative option. An important factor of the QRP model is its incorporation of intercrop relationships in the form of a covariance – variance matrix. Crops with high variances may still prove attractive in a portfolio if their returns covary negatively with other crops in the portfolio (Hazell & Norton, 1986). This explains the models attraction to groundnuts despite its relatively high variance as it covaries negatively with both sweet potatoes and common beans.

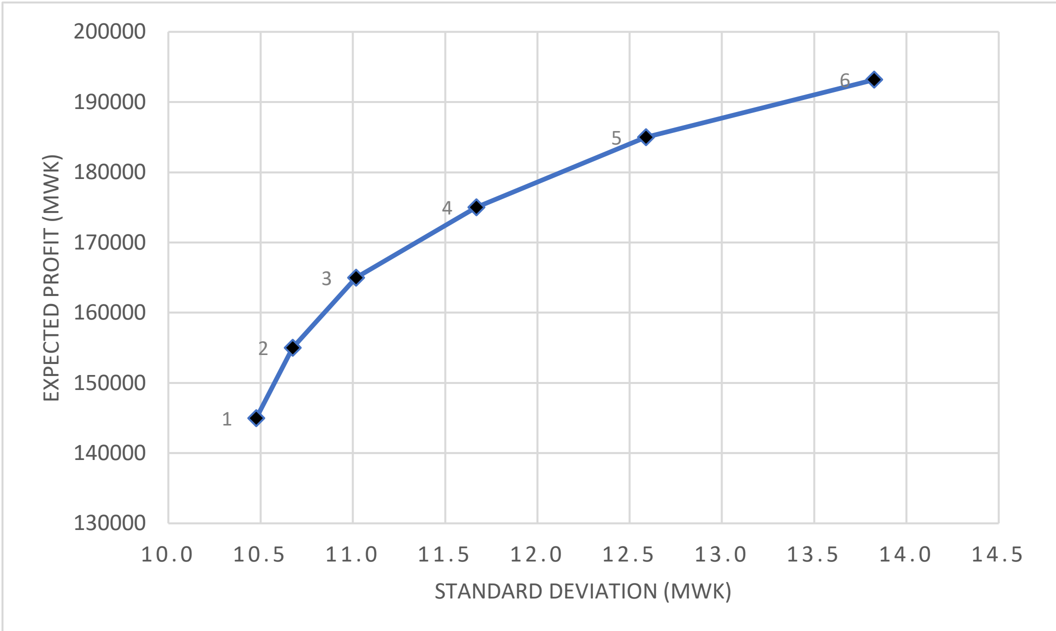

Figure 5.2 E,V frontier for small farms with fertiliser

In Figure 5.2, the shape of the E, V frontier indicates that initially, a large gain in expected profit can be achieved at the expense of a small amount of additional risk. Such a phenomena is particularly prominent moving from run 1 to run 3, which sees a 14% increase in expected profit from MWK145 000 to MWK165 000 at the cost of 11% added risk. The model suggests such a change is brought about by increasing the land allocation to groundnuts and having a relatively impartial share of land to maize, groundnuts, beans and sweet potatoes.

Moving further right along the E, V frontier from run 3, a continued increase in groundnut allocation matched with a decline in bean production sees expected profits increase but at a lower rate than the increase in additional risk. This may still suit risk seeking farmers aiming to achieve higher expected profits. The portfolios that match the runs indicated on the E, V frontier in Figure 5.2 correspond to the allocations specified in Table 5.2.

To summarise the risk minimising strategies for small farms using fertiliser, maize is consistently grown at its minimum level across all the portfolios matched with sweet potatoes grown at its maximum constraint. Thus, the main variations after the allocation of land to maize and sweet potatoes is mostly attached to groundnuts and beans. More risk more reward is mostly seen through an increase in the allocation of land to groundnuts at the expense of the stable bean crop. Unlike the unfertilised small farm scenario, the fertilised model suggests very small amounts of soybeans should be grown as shown in Table 5.2.

5.2.3 Medium farms with no fertiliser application

The medium farms are categorised by land sizes between 2 to 4 acres. Although this category falls above the above smallholder farm size in Malawi, the large proportion of the population involved in agriculture means there is still a large sample of farmers within this category. In the small farm category, the minimum maize constraint occupied a large portion of the available land. With a larger remaining area available after allocating land to maize, the significance of the other crops in the risk minimising strategies becomes more prominent in the medium and large farms.

Table 5.3 Portfolio results for a medium farm with no fertiliser

Run	1	2	3	4	5	6	7
Expected profit (MWK)	195 000	205 000	215 000	225 000	232 000	239 079	245 000
Standard Deviation (MWK)	11 860	12 020	12 200	12 380	12 660	13 120	13 120
Maize	1,3	1,3	1,3	1,3	1,3	1,3	Infeasible solution
Groundnuts	1,85	1,99	2,14	2,34	2,53	2,7	
Beans	0,36	0,37	0,37	0,31	0,17	-	
Sweet Potatoes	0,125	0,122	0,12	0,05	-	-	
Soybeans	-	-	-	-	-	-	
Total usage	3,635	3,782	3,93	4	4	4	

The maximum attainable profit derived from linear programming is MWK239 079 for a medium farm not using fertiliser. The frontier was created by decreasing this value in MWK10 000 increments except for run 6, which was used to bridge the uneven gap from the unrounded profit maximising portfolio. Table 5.3 indicates that maize is allocated at the minimum level across all the runs. A deeper look at the marginal values attached to the maize minimum for the different runs indicate high marginal values. For example, on run 6, the marginal value of the maize minimum is MWK 14 145. The marginal value is an indication of the effect of an increase in the maize minimum by one unit on the objective.

In this study, the objective is to minimise variance or in this case standard deviation (risk), so the marginal value here indicates a unit increase in the maize minimum will increase the portfolio standard deviation by MWK 14 145. This high value explains why the model always allocates the minimum amount of land to maize. Nonetheless, its importance as a food source is crucial in the subsistence farming environment adopted in Malawi.

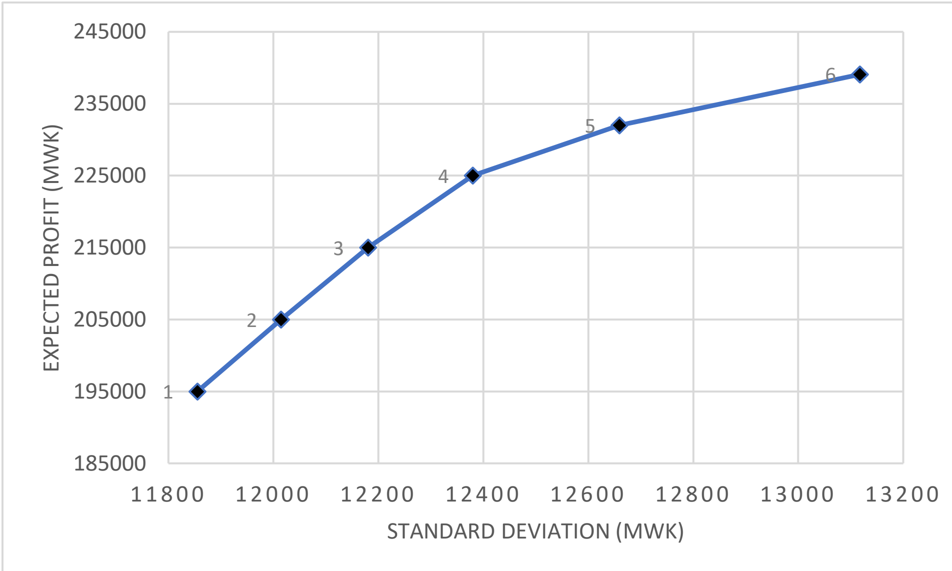

Figure 5.3 E,V frontier for medium farms with no fertiliser

The E,V frontier in Figure 5.3 reveals the diminishing relationship between risk and reward to be more significant towards the profit maximising portfolio. The less risky side of the E, V frontier has a more prolonged steep slope until run 4. This indicates that until run 4, more reward can consistently be earned at the cost of a smaller amount of additional risk, in comparison to what would be required to earn more reward from run 4 onwards. Looking at the corresponding results in Table 5.3, from run 4 onwards a noticeable decline in the allocation of land to the stable bean crop is seen together with a decline in sweet potatoes. The accumulated decline is matched with an increase in groundnuts until the point is reached in the profit maximising portfolio where only maize and groundnuts are grown.

To summarise the diversification risk strategies for a medium farm not using fertiliser, groundnuts are the pivotal crop growing in proportional share as expected profit and risk increases. The least risky portfolio is made up of maize at its minimum level, groundnuts as the dominant share, followed by decreasing amounts of beans and sweet potatoes. As riskier yet rewarding portfolios are desired, land allocated to beans and sweet potatoes is substituted with groundnut and minimally constrained maize production. Like with unfertilised small farms, the model excludes the inclusion of soybeans in any of the portfolios.

5.2.4 Medium farms with fertiliser application

Fertilizing a small field is more financially attainable, which is why barely fifty percent of farmers outside the small farm category are able to afford enough fertiliser for their larger farm (FAO, 2018). However, through input subsidy programmes such as FISP, access to fertilisers at subsidised rates allow farmers with higher capital levels (be it from of off-farm income or other sources), to fertilise their crops on a slightly larger scale. The use of fertiliser on maize results in higher yields, which means that less land needs to be allocated to maize to meet the food requirement per household, this leaves more land available for risk minimizing strategies.

Table 5.4 Portfolio results for a medium farm with fertiliser

Run	1	2	3	4	5	6	7
Expected profit (MWK)	300 000	310 000	320 000	330 000	340 000	354 290	355 000
Standard Deviation (MWK)	19 370	20 630	21 980	23 400	25 240	29 720	29 720
	Land allocation (Acres)						
Maize	0,75	0,75	0,75	0,75	0,75	0,75	Infeasible solution
Groundnuts	1,71	1,86	1,99	2,14	2,37	2,82	
Beans	0,56	0,4	0,24	0,07	-	-	
Sweet Potatoes	0,5	0,5	0,5	0,5	0,5	0,43	
Soybeans	0,29	0,32	0,35	0,38	0,23	-	
Total usage	3,81	3,83	3,83	3,84	3,85	4	

Table 5.4 shows the efficient risk minimising portfolios at the incremental expected profit levels. From the profit maximising figure, the expected profit was decreased parametrically in MWK10 000 increments. Across all the portfolios, the maize minimum acts as binding constraint together with capital – because not all the land is used. Sweet potato is generally produced at its maximum allocation until the profit maximising portfolio. As seen in Table 5.4, there is a growing inclusion of soybeans until the profit maximising portfolio which exempts risk minimizing strategies. Thus, this indicates the inclusion of soybeans to be a tool for risk minimization testament to its high negative covariance to the lucrative groundnut crop. The relationship between soybeans and groundnuts and its effect on risk and return is best witnessed on the E, V frontier.

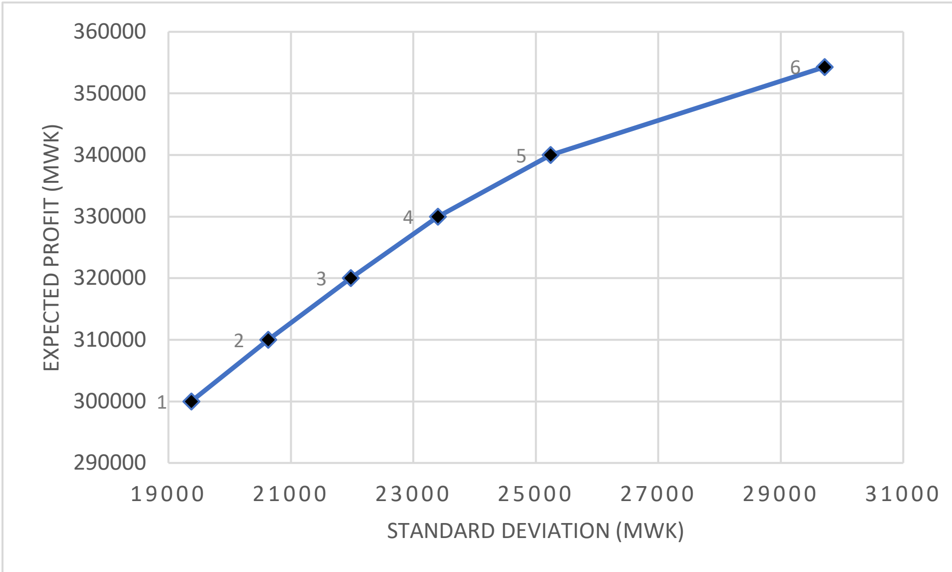

Figure 5.4 E,V frontier for medium farms with fertiliser

The growth in expected profit is primarily attributable to the increase in land allocated to groundnuts as seen in Table 5.4. To minimise risk, the model utilises the negative covariance between groundnuts and soybeans by increasing the soybean allocation as groundnut allocation increases. Initially, a larger increase in expected profit at the expense of a smaller amount of additional risk can be seen by declining the amount of beans produced and substituting it with groundnut and soybean production.

Moving across the frontier in Figure 5.4, the slope diminishes as the additional expected profit is attached with a growing amount of additional risk. A larger marginal decrease in bean acreage at this area of the frontier removes the 'stable' crop in place for the lucrative groundnut crop. Across the frontier, sweet potatoes are allocated their maximum limitation. A look at the marginal result generated by the model with reference to the sweet potato maximum, a negative value is found across all the runs.

In run 4, the marginal value for the sweet potato maximum constraint is – MWK 21 545. The negative sign indicates the effect of an additional unit of sweet potato on the objective. In this case, increasing the sweet potato maximum by one unit will decrease the portfolio standard deviation by MWK 21 545. One may think this is a bad thing but a reminder that the objective is to minimise risk, thus the increase in sweet potato decreases the amount of risk present in the portfolio - which is a desirable outcome. This highlights the potential for the crop, should storage and marketing capacities improve.

Overall, the portfolio results suggest for a more risk averse farmer that common beans should be grown in smaller, yet sufficient amounts compared to groundnuts – with an inverse relationship as extra profit is desired in increasing allocation to groundnuts. This, together with maize and sweet potatoes bound to their minimum and maximum levels respectively, provides a portfolio which does not utilise all the land available.

Therefore, the study recommends the adoption of secondary crops such as cassava and pigeon peas to fulfil the vacant land on the plots. As the expected profit increases, some of this vacant land is adopted by groundnuts and soybeans, which also substitute beans at an increasing rate. This is the first model to utilise soybeans in a notable manner which is primarily due to its negative covariance with groundnuts.

5.2.5 Large farms with no fertiliser

The large farm category, ranging between four and six acres of cultivable land, is the least populated category in this study. Larger fields require larger amounts of inputs, which is often the constraining factor in Malawi. Nonetheless, there are some farmers who have the capabilities of operating larger pieces of land. Anseeuw, Jayne, Kachule and Kotsoploulos (2016) identified that more than half the farmers in their study entered the large farm category after successful expansion out of small-scale farming. Other farmers in the large farm category were found to be urban-based professionals, entrepreneurs and/or civil servants who acquired land (Anseeuw *et al.*, 2016).

The potential to realise the most out of the diversification strategies and its effects on risk and return are exemplified in line with the increasing availability of land. After securing enough land to maize to secure food security to an extent, there remains sufficient land on which the various diversification portfolios can be implemented.

Table 5.5 Portfolio results for a large farm with no fertiliser

Run	1	2	3	4	5	6	
Expected profit (MWK)	305 000	320 000	335 000	350 000	365 000	379 947	385 000
Standard Deviation (MWK)	13 900	14 230	14 560	14 890	15 260	16 050	16 050
			Land allocation (Acres)				
Maize	1,3	1,3	1,3	1,3	1,3	1,3	Infeasible solution
Groundnuts	3,42	3,63	3,85	4,06	4,33	4,7	
Beans	0,4	0,4	0,4	0,4	0,35	-	
Sweet Potato	0,1	0,1	0,09	0,08	0,02	-	
Soybeans	-	-	-	-	-	-	
Total usage	5,22	5,43	5,64	5,84	6	6	

Table 5.5 shows the importance of groundnuts in the diversification strategy, given the minimum land allocation to maize across all the portfolios. Unlike the case when the crops are fertilised, the covariance between unfertilised groundnuts and soybeans is a large positive value. This means their coexistence is not as desirable in a risk-minimizing environment, hence the absence of soybeans in the portfolio results.

The profit maximising portfolio, which contains no risk-aversion element, comprises of only two crops - namely maize and groundnuts. Maize is bound to its lower limit. When risk-aversion strategies are implemented, the diversification of the portfolios increase with subtle, yet constant amounts of common beans introduced and declining minor amounts of sweet potatoes moving from left to right on Table 5.5. The E, V frontier was generated in conjunction with MWK15 000 increments decreasing from the profit maximising portfolio derived using linear programming.

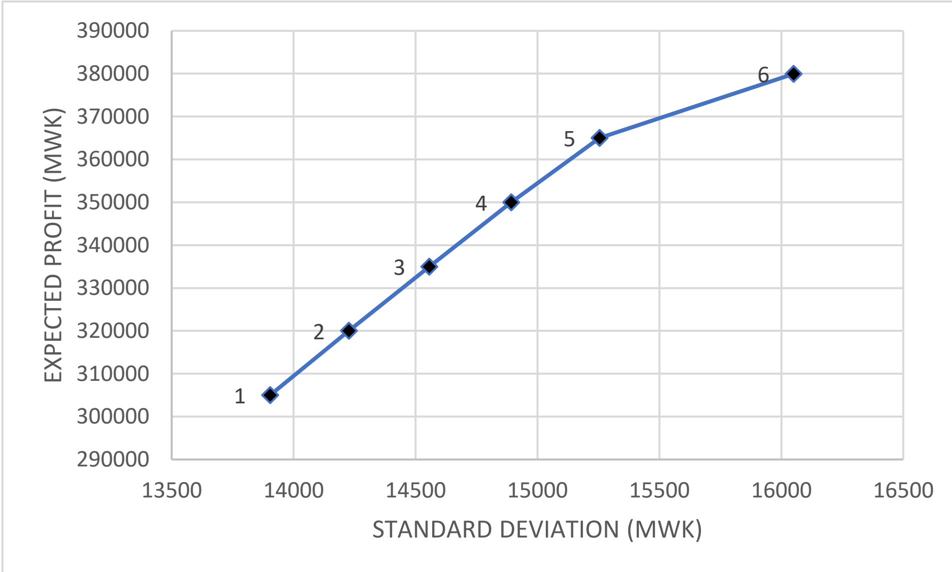

Figure 5.5 E,V frontier for large farm with no fertiliser

The diminishing rate of the slope of the E, V frontier in Figure 5.5 is not as prominent as it is in the small farm category. This is because of the size of the parametric increments relative to the profit maximising figure. The shapes of the E, V frontiers in this study are unique as they portray the minimum standard deviation to match a prespecified profit. Therefore, the shape of the curve may differ from other E, V frontiers which prioritize maximising profit and plot the matching variance.

In Figure 5.5, the noticeable marginal relationship between risk and return comes between run 5 and 6. Run 6 is the profit maximising portfolio, as soon as risk minimising strategies are implemented as is the case for run 5, the level of risk declines substantially and only forfeits a less significant amount of expected profit. The difference between run 5 and 6 echoes the importance of diversification also shown in Table 5.5 where the supplementary crops in the portfolio of run 5 compared to run 6 are shown.

In addition to prioritizing land to groundnuts and then maize, the portfolio also includes a portion of bean production and minor amounts of sweet potato. The influence of substituting these crops at the expense of a bit of groundnut allocation hardly jeopardizes the expected profit but remarkably reduces the exposure to risk. To further promote diversification and to utilise the vacant land illustrated in most portfolios in Table 5.5, the study recommends the adoption of the intercropped crops mentioned in Chapter 4. Cassava and pigeon peas can provide much needed cash flow later in the season when the primary crop is sold off or consumed given their later maturing stage.

Large farms not using fertiliser looking to use diversification to minimise their exposure to risk are recommended to allocate enough land to maize to ensure an extent of food security. Following this, land allocation to groundnuts should increase in line with the level of risk the farmer is willing to take. With groundnuts as the pivotal crop, with maize grown at its minimum level, common beans can be grown in reasonable amounts followed by a small portion of sweet potatoes. Like the case with the other unfertilised farm categories, the model suggests large unfertilised farms should avoid the production of soybeans when aiming to efficiently minimise risk.

5.2.6 Large farms with fertiliser application

Following the findings from Anseeuw *et al.* (2016), the ability of fertilizing larger area becomes more realistic in the smallholder context of Malawi. Thus, urban professionals and entrepreneurs possess the capability of having access to larger amounts of capital (through larger borrowing power or savings etc). These circumstances provide a few of the possibilities that may account for the farmers who can fertilise their large category farms.

Using linear programming, a profit maximising portfolio was generated. The expected profit from this portfolio is MWK527 321, this figure disregards any risk minimizing strategies. The portfolio revolves around the profitable groundnut crop in combination with sweet potato and maize, both bound to their maximum and minimum limitations respectively

Table 5.6 Portfolio results for a large farm with fertiliser

Run	1	2	3	4	5	6	
Expected profit (MWK)	430 000	450 000	470 000	490 000	510 000	527 321	530 000
Standard Deviation (MWK)	29 020	31 520	34 250	37 160	40 490	46 490	46 490
			Land allocation (Acres)				
Maize	0,75	0,75	0,75	0,75	0,75	0,75	Infeasible solution
Groundnuts	3	3,28	3,56	3,83	4,22	4,75	
Beans	1,2	0,87	0,54	0,22	-	-	
Sweet Potatoes	0,5	0,5	0,5	0,5	0,5	0,5	
Soybeans	0,49	0,55	0,61	0,67	0,52	-	
Total usage	5,94	5,95	5,96	5,97	5,99	6	

From Table 5.6, it can be seen by immediately introducing risk minimising strategies from run 6 to run 5, the model substitutes some land allocation away from groundnuts in place for soybeans. The negative covariance between the two crops contributes to the notable decline in the portfolio standard deviation at the cost of a less significant amount of expected profit – as seen by the shallow slope between run 5 and 6 in Figure 5.6 below.

Maize production is confined to its minimum level across all portfolios, while sweet potatoes are limited to its maximum constraint. The marginal value of maize minimum variable is positive across all the constraints in contrast to the sweet potato maximum marginal value which is negative across all the portfolios. If the model forced an increase in the maize minimum, it would increase the portfolio standard deviation following the positive marginal value. As for sweet potato, if the model increased its maximum constraint, the portfolio variance would decrease as indicated by the negative marginal value. This further prompts the need to improve sweet potato marketing and storage facilities.

Further to the maize minimum and sweet potato maximum constraints, the model is also bound by the capital constraint, especially given the poor nature of most smallholder farmers in Malawi and the corresponding higher inputs costs to fertilise a larger farm. Nonetheless, the model generates a diverse portfolio which utilizes almost all the available land. Common beans are more popular among the risk-averse portfolio levels given its low variance. As the risk tolerance levels increase, land is substituted away from beans to groundnuts and soybeans.

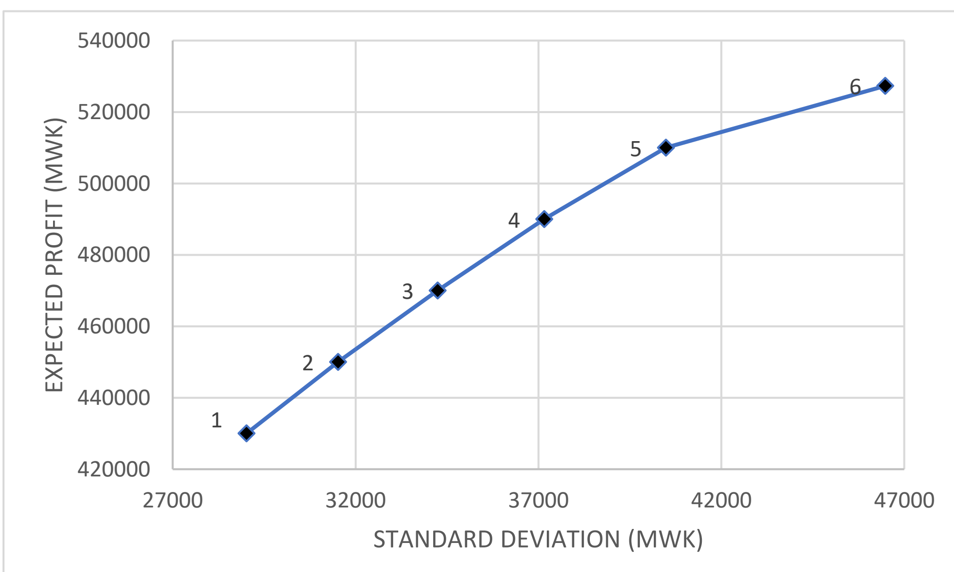

Figure 5.6 E,V frontier for large farm with fertiliser

The steeper the slope of the frontier in Figure 5.6 the greater the additional expected profit against the additional risk. As the slope gradient decreases, additional risk exposure is needed to achieve additional expected profits. When grown in conjunction, groundnuts and soybeans can provide sufficient returns, whilst the negative covariance between the two crops ensures the level of risk exposure remains manageable.

Any portfolio lying below the frontier is feasible yet inefficient, the same expected profits could be achieved at lower levels of risk. A portfolio lying above the frontier is unattainable given the respective constraints in place. Portfolios, like the ones illustrated in Table 5.6, lie on the frontier and are therefore efficient portfolios in terms of the risk – return trade-off.

Large farms using fertiliser have the ability to achieve significant benefits when using diversification for efficient risk managing strategies. The ability of groundnuts to achieve profitable results, while using the negative covariance of soybeans to provide an efficient risk minimising combination, is used across various levels of potential risk. Aside from this combination, sweet potatoes and maize are consistently grown at their constraining levels. Adding common beans to the portfolio provides an efficient diversification mix for less risky farmers.

5.2.7 Validity measure of the models

Validity can be defined as the degree to which variables accurately capture and measure what they are supposed to measure ((Hair, Black, Babin & Anderson, 1987) cited by (Kobzar *et al.*, 2002)). For the models used in this study, the validity of each model was checked by creating a run with an expected profit value higher than the profit maximising value derived using linear programming. When this validity checking value was inputted into the model, the results generated read "infeasible solution", which can be seen in the portfolio results table of each model above. This validates the accuracy of the models as figures above the maximum logical value should not be attainable given the constraints in place.

Furthermore, several runs in a few of the models above generated portfolio results which do not utilise all the available land. This is another indication which validates the reliability of the model to capture accurate results. Logically, one could expect that when the expected profit is reduced parametrically far enough below the profit maximising figure, then it would not require all the land to reach the lower expected profit with risk minimization as the objective. Such is the case with the models above, which further solidifies their validity to capture the diversification strategies which minimise the exposure to risk for the smallholder famers of southern Malawi.

5.3 Discussion and recommendations

All the models run in this study to accommodate the various scenarios identified, were bound to the minimum maize allocations. Evidently, maize is not the most profitable nor efficient risk-minimising tool out of the crops used in the study. However, the study's objective to analyse the use of diversification as a tool to minimise risk is based on the desperate need to ensure smallholder farmers can afford basic living requirements, support their families and most importantly be food secure. Thus, in a country like Malawi where these factors are a struggle on an annual basis, it is crucial to address the food insecurity issue.

Modern-day expectations tend to focus more on profit maximisation and disregard the basics of ensuring food security first. Maize forms an integral part of this and its importance to a self-sufficient smallholder farmer is paramount. After ensuring a large proportion of their stable food, the remaining land was diversified to minimise exposure to risk.

Common beans were identified to be the most stable, run-of-the-mill crop with land allocations remaining relatively low particularly when higher profits are desired. When farmers have the ability to fertilise, sweet potatoes showed extremely attractive results, their land allocation was constantly limited to its maximum constraint on fertilised lands. Its ability to generate sufficient returns with low variances across the study period make it an all-round desirable asset to have in a diversified portfolio.

The marginal values attached to the maximum sweet potato crop in the fertilised models indicate the importance to establish efficient storage and marketing facilities for the crop. The production potential is there, and the demand is by no means shy, which means the country needs to establish a way to connect the two and allow for sweet potato production to reach its full potential. Currently, the bulkiness and pure volume of too much sweet potato overwhelms most smallholder farmers who lack the facilities to store or process the crop. Should processing cooperatives and/or storage capacities facilitate the emergence of sweet potatoes from the limitations of informal market sales, then the influence of the crop in a diversified portfolio can become more effective.

Sweet potatoes also had a place in the unfertilised diversification portfolios, although never on the same scale as the fertilised sweet potato crop. The low variance of the unfertilised sweet potato makes it attractive at lower expected profit levels where risk exposure is low.

Soybeans were almost completely ignored in the unfertilised models, its high variance was not sufficiently counteracted by high profit levels, which means for smallholders who lack the ability to fertilise, the study suggests excluding soybeans from their portfolio for the most part. As for fertilised soybeans, its role in the diversification strategies to minimise risk is rather useful. Its negative covariance with probably the most lucrative crop in this study – groundnuts, makes it a prominent part of a diversified portfolio. As higher expected profit levels are matched with high levels of groundnut production, corresponding soybean production is used as a strategy to lower the overall variance of the portfolio.

Therefore, the two crops go hand in hand when used in a diversification portfolio looking to minimise risk. Groundnuts proved to be attractive for all the models created in this study. Msusa (2007) also found groundnuts to be the crop which required increased attention and inclusion in a farmer’s portfolio.

Groundnuts feature at all risk levels but are especially prevalent when higher expected profit margins are desired. Currently, high aflatoxin levels plague the groundnut sector in Malawi. The knock-on effects can extend as far as export bans on the product, which would hamper the demand and thus the price of groundnuts. Several strategies can be adopted to reduce the levels of aflatoxins in groundnuts from early planting right up to proper drying and storage (ICRISAT, 2016). If Malawi can address the aflatoxin issues in the groundnut crop, there lies even further potential for the crop in the export market, which would bring in valuable foreign exchange for the country.

A crucial determination of these findings is that crop prices are labelled at the government-imposed farm gate prices. When government is unable to protect its farm gate prices, which serve as the minimum price for a crop, the level of risk exposure becomes vast. No longer can the smallholder do his/her bit to combat the production risks that they face but now they also face market risks, which are even further out of their control.

Local vendors often exploit the sudden oversupply of a crop during the harvest periods, which drives the prices down, often below farm gate levels. Without much bargaining power, farmers are forced to sell their crop at the prices offered by the local vendors who then go on and sell it in the local markets or towns. There are cases when a crop is in high demand and/or supply is low, and vendors offer prices well above farm gate prices. However, this can vary from village to village within southern Malawi, which further indicates the need for the government to implement a facility which secures crop prices and minimises the market risks borne by smallholder farmers.

A state-owned marketing platform currently exists known as ADMARC (The Agricultural Development and Marketing Corporation); their objective was to promote the Malawian economy through increasing the agricultural sectors influence in both local and international markets. Moreover, they strive to develop new foreign markets and aid local smallholder farmers. However, mismanagement and inefficiencies have deteriorated the theoretically sound strategy, forcing smallholders to source other local markets and/or vendors were the prices are exploited.

The importance to reignite and develop such a marketing board will not only provide smallholder farmers with sense of security regarding market risks, but will also provide the country as a whole with the opportunity to source international markets and bring in much needed foreign exchange. The country has the land, the knowledge and the climate to use agriculture as a driving force for the economy, the existence of such a marketing platform will take the country's agricultural potential to the next level.

5.4 Conclusion

The importance of diversification is a growing revolution. Its relevance and motivation to agriculture and more specifically Malawian agriculture has been brewing for many years, with multiple studies identifying the level of diversification in the country and the other determinants thereof. This chapter has furthered the importance of diversification by analysing at the farm level the most optimum ways of diversifying with risk minimisation as the objective.

The chapter provides a practical breakdown of what the diversified portfolios should look like at different levels of risk for a wide range of smallholder farmer categories found in southern Malawi. The performance of each crop is further enhanced by an analysis of its interrelationship with other crops over the study period, which provided the basis on which the model derived the risk-minimising combinations to achieve prespecified profit levels.

The influence of groundnuts was significant, with all models indicating the need to include a noticeable proportion of the crop in the farmer's portfolios. Its significance was particularly visible in the medium and large farm categories where the results suggest on average for more than 50 percent of the arable land to be allocated to groundnut production.

Following this, the chapter touched on the importance of limiting the damage of aflatoxins on the local groundnut industry in an attempt to maximise the potential of the crop both locally and in the international markets. The results indicate that the nutritious sweet potato should be grown at its maximum limitation of half an acre in the fertilised medium and large farm categories. However, this surfaced the processing and storage shortfalls found in Malawi, which limit the ability of the crop to realise its full capacity.

Chapter 6: Conclusion

6.1 Introduction

In the wake of the necessity for Malawian smallholders to diversify away from tobacco, this study provides a practical answer for smallholder farmers looking for alternatives. Mango *et al.*, (2018) and Msusa, (2007) were among several studies which highlight the need to diversify farming practices held by Malawian smallholder farmers - particularly those reliant on tobacco. This study uses the largely theoretical literature and applies its findings to the farm level to provide farmers with the next step in the journey to diversify. The focus of the study is to implement the diversification approach as uttered by all the previous studies and use it practically on the farm level - with the aim to achieve sufficient returns while minimising the level of risk taken. Following this, the study identifies several portfolios comprised from prespecified crops to suit farmers from various model backgrounds.

This chapter provides a final overview of the study by providing a summary of the steps used in this study approach. The chapter then presents a concise summary of the findings in this study and the implications thereof. Lastly, recommendations for the scope for further research based on the conception of this thesis is offered.

6.2 Thesis overview

This thesis began by highlighting the importance of agriculture to Malawi. The sector has been the backbone of the country's economy and the livelihoods of her people. To some extent, this reliance could be pegged down to a single crop – tobacco. In the wake of the turbulent, weakening "green gold" tobacco market, many studies have endorsed the extensive need to diversify Malawian agriculture. The urge comes not only at the macroeconomic level, but also to guide the local smallholder farmers away from the growing threats of poverty and food insecurity.

After a thorough review of literature and past studies targeting diversification within agriculture both internationally and in Malawi, the benefits it has on risk management became clear. Several literature sources present the determinants of diversification in Malawi and the current level of diversification held in the country, but few provide the answer of how to diversify on the practical farm level.

This study took on the task to fill this gap and provide the practical guidance needed by the smallholder farmers. With risk minimization at the core of the study, the literature review highlighted the use of quadratic risk programming as a tool to generate a portfolio of crops, which would minimise risk at prespecified return levels.

Quadratic linear programming can be considered a renovation to the more commonly used linear programming. The quadratic counterpart replaces mean deviations found in linear programming with a variance – covariance matrix. This provides the quadratic nature to the more complex of the two programming methods, which allows for interrelationships between crops to be incorporated in the objective of the model.

As risk minimisation is the objective of the quadratic programming model, it is crucial to incorporate the variance – covariance matrix to comprehend the interrelationships between the crops. The model can generate portfolios that would minimise the level of risk at a prespecified return level. The results are best displayed on an efficient risk return frontier which allows for a visible analysis of the relationship between the amount of risk exposure required to achieve a desired level of return.

After categorising smallholder farmers in southern Malawi according to their farm size and whether they applied fertiliser or not, the study formulated six different quadratic risk programming models. After coding the data and implementing the respective constraints to suit each farm category, the models were run to generate the efficient risk return frontier. Each farm category had its own risk return frontier, which corresponded to a table which displayed the portfolio responsible for each point on the frontier. The portfolios comprised of different amounts of land to be allocated to the selected crops. These results answer the objective of this study as to how a smallholder farmer in Malawi can use diversification at the farm level to efficiently manage his/her risk considering their financially constrained environment. A discussion of the results and the challenges regarding their implication was then addressed.

6.3 Summary of major findings

The results suggested that the inclusion of groundnuts within a diversified crop portfolio both reduces risk and improves expected income for Malawian smallholder farmers. The impact of the inclusion of groundnuts is greatest among the medium and large farm size categories where the results indicate around 50 percent of the arable land in a diversified portfolio should be allocated to groundnut production. Among the subset of farmers who use fertiliser the inclusion of groundnuts and soybeans improved the diversification outcomes given the good returns of groundnuts matched with its negative covariance with soybeans, thereby reducing the risk of the overall portfolio whilst increasing the expected income. In a large fertilised farm, 3,6 acres of groundnuts combined with 0,6 acres of soybeans results in an increase in expected profit of MWK 40 000 at the expense of an increase in variance of only 28 percent. When grown alone, groundnuts could achieve the same expected profit but with a much larger variance attached to it. However, it must be mentioned that the optimised performance of the groundnuts assumes the effective management of aflatoxins which pose a potential threat to the modelled outcomes.

In the small farm size categories, the results showed that these famers should allocate most of their acreage to maize: non-fertilising farmers would obtain the best result by allocating 1.3 of their 2 acres to maize whilst fertilising farms should allocate 0.75 of their 2 acres to maize. Given that maize serves as a staple crop, the model was constructed such that a minimum amount of maize had to be produced to meet household subsistence requirements. The results showed that this minimum level was not exceeded in any of the study categories given the relatively low profitability of maize.

Given a limited market and insufficient storage capacities, the other production constraint targeting a specific crop was a maximum sweet potato constraint which limited the amount of land allocated to sweet potatoes in the model. The results showed that fertilised sweet potatoes were consistently bound to their upper limits and thus more of the crop would have been added if this constraint were to be relaxed. For example, in Run 5 of the large fertilised farms, the marginal value of the sweet potatoes is 18 047 which means an increase in the amount of sweet potatoes grown by one unit reduces the portfolio standard deviation by that amount. This shows the ability of sweet potatoes to efficiently reduce the overall variance of a portfolio. Whilst the demand and potential supply for sweet potatoes exists, the challenges with storage and processing must be addressed.

6.4 Implications of major findings

This study has shown that not only is it important to establish optimal diversification portfolios, but it also important to distinguish between different farm sizes and cultivation practices, specifically the use and non-use of inorganic fertiliser. The negative covariance between groundnuts and soybeans on fertilised farms proved to be among the major influential findings of this study. Groundnuts provide the most attractive returns but come at the cost of a higher variance. When combined with the negative covariance with soybeans, the overall portfolio variance is optimised.

The extensive literature review of the quadratic risk programming model adequately highlights the ability of negative covariances within a portfolio to be an integral part of efficient risk minimisation. Thus, to the farmer, the combination of groundnuts and soybeans as part of a crop portfolio for fertilised farms is an attractive feature. The input costs of the two crops on a fertilised farm are similar, with soybeans being slightly more expensive due to the seed cost. Nonetheless, the land and labour preparations topped with similar fertiliser applications revealed by the study data, make it easy for the two crops to be grown under the control of a single smallholder farm

Considering the validity of the models, several portfolios produced results which did not utilise all the available land. The models derived a portfolio that would produce the expected profit levels at an efficient risk level without having to use all the available land. Given the strive to enhance the diversification strategies of smallholder farmers in southern Malawi, the study promotes the use of secondary crops (Cassava, Pigeon Peas, Pumpkin) to fill the vacant land left in the models. Literature reviews of the secondary crops included in this thesis support the adoption of pigeon peas as a 'boundary' crop for utilising the available land. The ability of the secondary crops utilise residual fertility from the primary crops means their adoption of the vacant land will provide beneficial results.

The findings in this study relating to the sweet potato maximum constraint in fertilised fields and its prevalent marginal value, indicates that it has underutilised potential. However, this would require investments storage facilities, processing and a marketing platform to unlock the potential of the crop. In the current storage, processing, and marketing situation results on a situation where local markets flooded are with large volumes of sweet potatoes over a short period of time, thereby driving prices down which limits to the quantity of sweet potatoes farmers can produce.

The results of this thesis indicate the potential that is being missed out on in the latter scenario. The current situation of Malawis underutilised sweet potato sector highlights the need to implement storage facilities or better yet develop the processing sector. An efficient processing sector will not only provide a market for the auspicious crop but also the opportunity to value add and grow the product onto the international market to see its beneficial effects felt on the macroeconomic scale. Government intervention which supports and facilitates the evolution of the processing sector in terms of legislation and policy will encourage the development of such a sector.

Although some results were unique to each category, others were common to all models and can be used to guide government policy and improve the general agricultural environment. The imperative role of the government to protect the farm gate prices they implement determines the efficiency with which the results of this thesis can hold.

While the study provides the results which combat production risk as far as possible, the farmers exposure to market risk is greatly influenced by the exploitation of the minimum price levels imposed. The formulation of a marketing platform regulated by the state is important to enhance the protection of such prices and further provides the country with the opportunity to take its peoples produce into international markets.

Such a platform run by the government does exist in the form of ADMARC. However, mismanagement has led to uncertainty and inefficiencies around the corporation. A large contributor to the concerns surrounding ADMARCs functionality is the buying period in which farmers can sell their produce. Promises were made in the 2020 season for the corporation to start buying crops in April and continue buying till August, yet many such as Frighton Njolomole – the President of the Farmers Union of Malawi, have expressed their disappointment over ADMARCs inability to efficiently budget allocated funds across the buying period (Mphatso, 2020).

The shortened buying window and mismanagement of allocated funds results in farmers missing the opportunity sell to ADMARC at the farm gate prices and are forced to sell to local vendors where they are exploited by low prices. The extension of the buying window held by ADMARC together with an allocated budget which sufficiently covers the buying period, will provide the farmers with a secure, controlled market to sell their produce to. The benefits of an extended buying period also mean the government has more maize and other produce readily available in times of the year that would otherwise see shortages and hunger - without having to address storage amenities.

This thesis based its analysis off the known theory that greater diversification will reduce risk. However, its contributions extended further than the theoretical realism in which diversification exists. This study provided a model for each of the common smallholder farmer groups found in Southern Malawi and provided each group with a practical way forward in using diversification to reduce risk. Like most optimisation studies and other research based off historical data, the sustainability of the results is not infinite. There will come a time when the accuracy of the findings may diminish, and an updated data set will need to be implemented. Nonetheless, this thesis provided a model which acts as the foundation for future optimisation studies focusing on reducing risk and provided practical results which are applicable at the time of this study.

6.5 Recommendations for further research

The data intensive nature of this thesis meant there were certain assumptions and limitations which needed to be made. Most of these shortfalls were primarily attributable to the availability of data. Given the study environment and period within which this thesis was written, the study was unable to generate enough of its own primary data and was therefore reliant on secondary data from a range of sources.

Although the study standardised the data requirements to allow for a fluent integration of data from various sources, there may be discrepancies out of this study's reach. Therefore, further research is to be done off the basis of this thesis with opportunity to conduct primary research on the relevant data segments. This would allow the basis of this study to extend its reach to not only a wider crop range but also the introduction of livestock into the portfolio and other assets such as off-farm income.

Although multiple industry organisations assisted extensively in providing the required data, the study was limited to a three-year period in conjunction with the data availability. To increase the accuracy of the results, further research may be conducted in the years to come to build upon the three-year period used in this study. The longer the period, the more accurate the trends analysed and particularly, the more accurate the interrelationships displayed in the variance – covariance matrixes.

Given the findings of this thesis, the mismanagement of the government regulated marketing platform was exploited. The need to ensure the protection of the farm gate prices was reiterated time after time. Further research into providing incentives or regulations to secure farm gate prices and prevent the overexploitation of market powerless smallholder farmers would allow for a system which promotes the incorporation of the results of this thesis and the diversification strategy as a whole.

Chapter 7: References

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